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Carl Sagan

BROCA'S BRAIN

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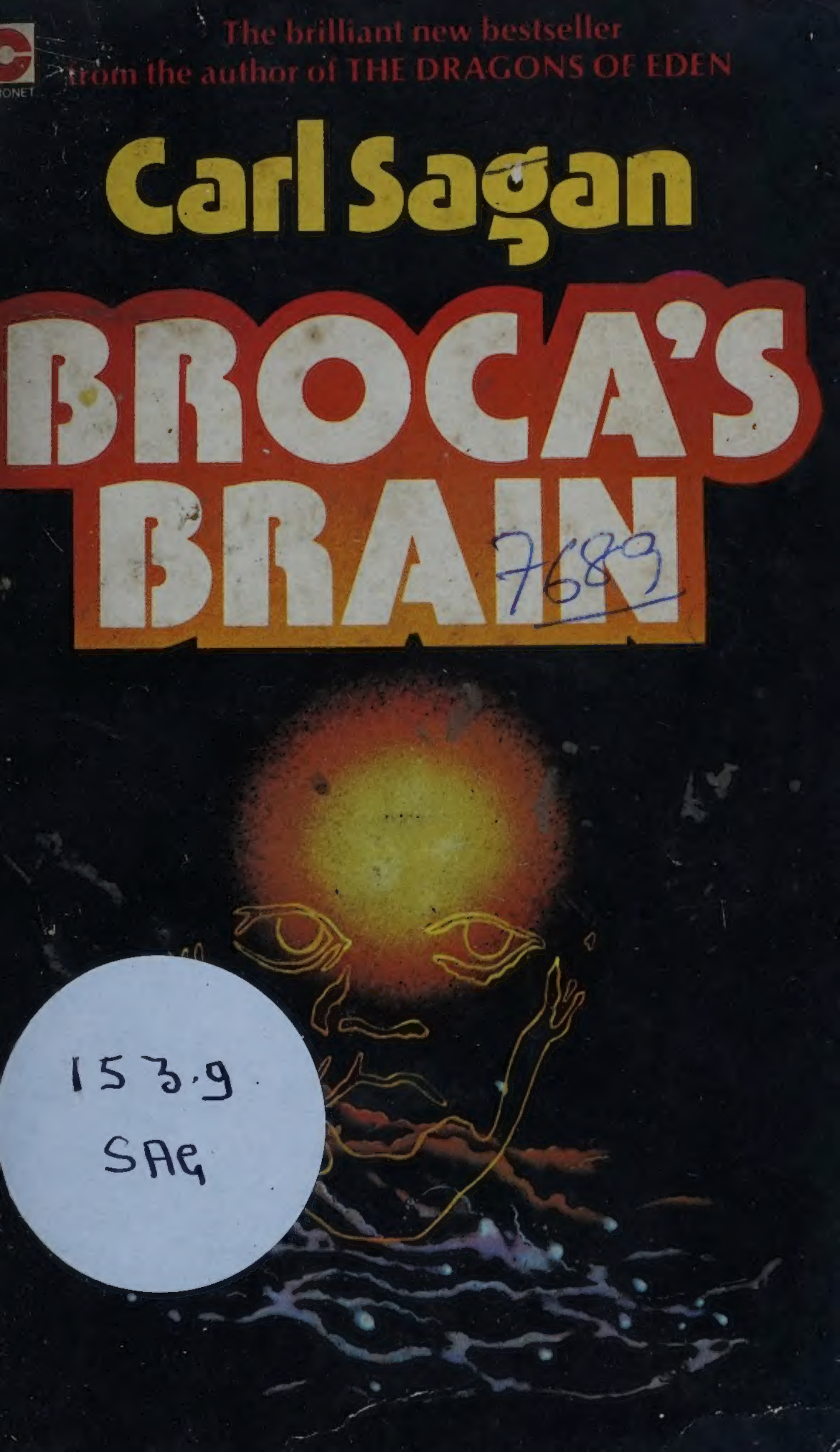

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BROCA'S BRAIN

Today science is about to penetrate many of the deepest secrets of the universe. We may be the first human beings to have scientific answers to the questions of the origins of consciousness, life, the Earth, and the solar system. We may know if there is intelligent life on other planets. We may discover how our universe began – and how it will end. 'We have entered, almost without noticing, an age of exploration and discovery unparalleled since the Renaissance,' writes Dr. Sagan, scientist, astronomer and NASA medallist who won the Pulitzer Prize for *The Dragons of Eden*. In BROCA'S BRAIN he probes the frontiers of the sciences of Earth, space, and the human mind, and previews the astonishing range of scientific knowledge that will soon be ours.

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BROCA'S BRAIN

The Romance of Science

Carl Sagan

CORONET BOOKS
Hodder and Stoughton.

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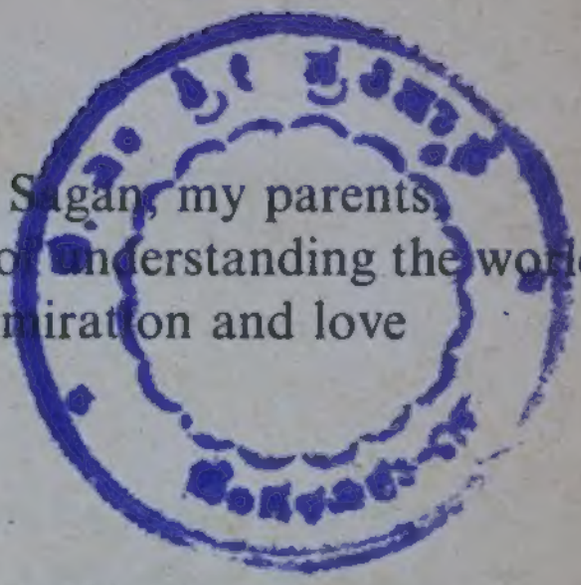
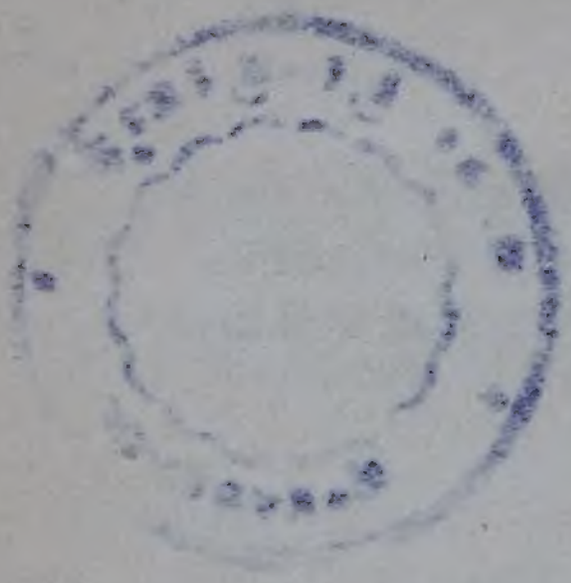
To Rachel and Samuel Sagan, my parents,
who introduced me to the joys of understanding the world,
with gratitude and admiration and love





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INTRODUCTION

WE LIVE in an extraordinary age. These are times of stunning changes in social organization, economic well-being, moral and ethical precepts, philosophical and religious perspectives, and human self-knowledge, as well as in our understanding of that vast universe in which we are embedded like a grain of sand in a cosmic ocean. As long as there have been human beings, we have posed the deep and fundamental questions, which evoke wonder and stir us into at least a tentative and trembling awareness, questions on the origins of consciousness; life on our planet; the beginnings of the Earth; the formation of the Sun; the possibility of intelligent beings somewhere up there in the depths of the sky; as well as, the grandest inquiry of all – on the advent, nature and ultimate destiny of the universe. For all but the last instant of human history these issues have been the exclusive province of philosophers and poets, shamans and theologians. The diverse and mutually contradictory answers offered demonstrate that few of the proposed solutions have been correct. But today, as a result of knowledge painfully extracted from nature, through generations of careful thinking, observing and experimenting, we are on the verge of glimpsing at least preliminary answers to many of these questions.

There are a number of themes that weave through the structure of this book, appearing early, disappearing for a few chapters, and then resurfacing in a somewhat different

context – including the joys and social consequences of th scientific endeavour; borderline or pop science; the no entirely different subject of religious doctrine; the explora tion of the planets and the search for extraterrestrial life and Albert Einstein, in the centenary of whose birth thi book is published. Most of the chapters can be read in dependently, but the ideas have been presented in an orde chosen with some care. As in some of my previous books I have not hesitated to interject social, political or historica remarks where I thought they might be appropriate. Th attention given to borderline science may seem curious t some readers. Practitioners of pop science may seem curiou to some readers. Practitioners of pop science were onc called Paradoxers, a quaint nineteenth-century word used t describe those who invent elaborate and undemonstrate explanations for what science has understood rather well i simpler terms. We are today awash with Paradoxers. Th usual practice of scientists is to ignore them, hoping the will go away. I thought it might be useful – or at leas interesting – to examine the contentions and conceits o some Paradoxers a little more closely, and to connect an contrast their doctrines with other belief systems, both scientific and religious.

Both borderline science and many religions are motivate in part by a serious concern about the nature of the univers and our role in it, and for this reason merit our considera tion and regard. In addition, I think it possible that man religions involve at their cores an attempt to come to grip with profound mysteries of our individual life histories, a described in the last chapter. But both in borderline scienc and in organized religion there is much that is specious o dangerous. While the practitioners of such doctrines ofte wish there were no criticisms to which they are expected t reply, sceptical scrutiny is the means, in both science an religion, by which deep insights can be winnowed from dee

nonsense. I hope my critical remarks in these pages will be recognized as constructive in intent. The well-meaning contention that all ideas have equal merit seems to me little different from the disastrous contention that no ideas have any merit.

This book, then, is about the exploration of the universe and ourselves; that is, it is about science. The range of topics may seem very diverse – from a crystal of salt to the structure of the cosmos, myth and legend, birth and death, robots and climates, the exploration of the planets, the nature of intelligence, the search for life beyond the Earth. But, as I hope will emerge, these topics are connected because the world is connected, and also because human beings perceive the world through similar sense organs and brains and experiences that may not reflect the external realities with absolute fidelity.

Each chapter of *Broca's Brain* is written for a general audience. In a few places – such as 'Venus and Dr. Velikovsky', 'Norman Bloom, Messenger of God', 'Experiments in Space' and 'The Past and Future of American Astronomy' – I have included an occasional technical detail; but understanding such details is not necessary for understanding the overall flow of the discussion.

Some of the ideas in Chapters 1 and 25 were first presented in my William Menninger Memorial Lecture to the American Psychiatric Association in Atlanta, Georgia, in May 1978. Chapter 16 is based on a banquet address at the annual meeting of the National Space Club, Washington, DC, April 1977; Chapter 18 on an address at a symposium, commemorating the first liquid-fuel rocket flight, held at the Smithsonian Institution, Washington, DC, March 1976; Chapter 23 on a sermon delivered at the Sage Chapel Convocation, Cornell University, November 1977; and Chapter 7 on a talk at the annual meeting of the American Association for the Advancement of Science, February 1974.

This book is written just before – at most, I believe, few years or a few decades before – the answers to mar of those vexing and awesome questions on origins and fat are pried loose from the cosmos. If we do not destroy ou selves, most of us will be around for the answers. Had v been born fifty years earlier, we could have wondered, po dered, speculated about these issues, but we could have *do* nothing about them. Had we been born fifty years later, th answers would, I think, already have been in. Our childre will have been taught the answers before most of them w have had an opportunity even to formulate the question By far the most exciting, satisfying and exhilarating time t be alive is the time in which we pass from ignorance t knowledge on these fundamental issues; the age where w begin in wonder and end in understanding. In all of the fou billion-year history of life on our planet, in all of the fou million-year history of the human family, there is only on generation privileged to live through that unique trans tional moment: that generation is ours.

Ithaca, New Yor
October 197

PART I

SCIENCE AND HUMAN CONCERN

CHAPTER 1

BROCA'S BRAIN

* * *

'They were apes only yesterday. Give them time.'
'Once an ape – always an ape.' ...
'No, it will be different.... Come back here in an age
or so and you shall see....'

The gods, discussing the Earth, in the motion picture version of H. G. Wells, *The Man Who Could Work Miracles* (1936)

IT WAS A MUSEUM, in a way like any other, this Musée de l'Homme, Museum of Man, situated on a pleasant eminence with, from the restaurant plaza in back, a splendid view of the Eiffel Tower. We were there to talk with Yves Coppens, the able associate director of the museum and a distinguished paleoanthropologist. Coppens had studied the ancestors of mankind, their fossils being found in Olduvai Gorge and Lake Turkana, in Kenya and Tanzania and Ethiopia. Two million years ago there were four-foot-high creatures, whom we call *Homo habilis*, living in East Africa, shearing and chipping and flaking stone tools, perhaps building simple dwellings, their brains in the course of a spectacular enlargement that would lead one day – to us.

Institutions of this sort have a public and a private side. The public side includes the exhibits in ethnography, say, or cultural anthropology: the costumes of the Mongols, or bark cloths painted by Native Americans, some perhaps prepared especially for sale to *voyageurs* and enterprising French anthropologists. But in the innards of the place there are other things: people engaged in the construction of exhibits; vast storerooms of items inappropriate, because of subject matter or space, for general exhibition; and areas

for research. We were led through a warren of dark, must rooms, ranging from cubicles to rotundas. Researc materials overflowed into the corridors: a reconstruction a Paleolithic cave floor, showing where the antelope bone had been thrown after eating. Priapic wooden statuary fro Melanesia. Delicately painted eating utensils. Grotesqu ceremonial masks. Assagai-like throwing spears fro Oceania. A tattered poster of a steatopygous woman fro Africa. A dank and gloomy storeroom filled to the rafte with gourd woodwinds, skin drums, reed panpipes an innumerable other reminders of the indomitable human urg to make music.

Here and there could be found a few people actually en gaged in research, their sallow and deferential demeanou contrasting starkly with the hearty bilingual competence Coppens. Most of the rooms were evidently used for storag of anthropological items, collected from decades to mo than a century ago. You had the sense of a museum of th second order, in which were stored not so much materia that might be of interest as materials that had once been interest. You could feel the presence of nineteenth-centur museum directors engaged, in their frock coats, in *goni métrie* and *craniologie*, busily collecting and measurin everything, in the pious hope that mere quantificatio would lead to understanding.

But there was another area of the museum still mo remote, a strange mix of active research and virtually aban doned cabinets and shelves. A reconstructed and articulatin skeleton of an orangutan. A vast table covered with huma skulls, each neatly indexed. A drawer full of femurs, pile in disarray, like the erasers in some school janitor's suppl closet. A province dedicated to Neanderthal remains, in cluding the first Neanderthal skull, reconstructed by Marce lin Boule, which I held cautiously in my hands. It felt ligh weight and delicate, the sutures starkly visible, perhaps th

first compelling piece of evidence that there once were creatures rather like us who became extinct, a disquieting hint that our species likewise might not survive forever. A tray filled with the teeth of many hominids, including the great nutcracker molars of *Australopithecus robustus*, a contemporary of *Homo habilis*. A collection of Cro-Magnon skull cases, stacked like cordwood, scrubbed white and in order. These items were reasonable and in a way expected, the necessary shards of evidence for reconstructing something of the history of our ancestors and collateral relatives.

Deeper in the room were more macabre and more disturbing collections. Two shrunken heads reposing on a cabinet, sneering and grimacing, their leathery lips curled back to reveal rows of sharp, tiny teeth. Jar upon jar of human embryos and foetuses, pale white, bathed in a murky greenish fluid, each jar competently labelled. Most specimens were normal, but occasionally an anomaly could be glimpsed, a disconcerting teratology – Siamese twins joined at the sternum, say, or a foetus with two heads, the four eyes tightly shut.

There was more. An array of large cylindrical bottles containing, to my astonishment, perfectly preserved human heads. A red-mustachioed man, perhaps in his early twenties, originating, so the label said, from Nouvelle Calédonie. Perhaps he was a sailor who had jumped ship in the tropics only to be captured and executed, his head involuntarily drafted in the cause of science. Except he was not being studied; he was only being neglected, among the other severed heads. A sweet-faced and delicate little girl of perhaps four years, her pink coral earrings and necklace still perfectly preserved. Three infant heads, sharing the same bottle, perhaps as an economy measure. Men and women and children of both sexes and many races, decapitated, their heads shipped to France only to moulder – perhaps after

some brief initial study – in the Musée de l'Homme. Wh
I wondered, must the loading of the crates of bottled hea
have been like? Did the ship's officers speculate over coff
about what was down in the hold? Were the sailors heedle
because the heads were, by and large, not those of wh
Europeans like themselves? Did they joke about their car
to demonstrate some emotional distance from the lit
twinge of horror they privately permitted themselves to fe
When the collections arrived in Paris, were the scientis
brisk and businesslike, giving orders to the draymen on t
disposition of severed heads? Were they impatient to unse
the bottles and embrace the contents with calipers? Did t
man responsible for this collection, whoever he might b
view it with unalloyed pride and zest?

And then in a still more remote corner of this wing of t
museum was revealed a collection of grey, convolut
objects, stored in formalin to retard spoilage – shelf upe
shelf of human brains. There must have been someone who
job it was to perform routine craniotomies on the cadave
of notables and extract their brains for the benefit of scienc
Here was the cerebrum of a European intellectual who ha
achieved momentary renown before fading into the o
scurity of this dusty shelf. Here a brain of a convict
murderer. Doubtless the savants of earlier days had hop
there might be some anomaly, some telltale sign in t
brain anatomy or cranial configuration of murderers. Pe
haps they had hoped that murder was a matter of heredi
and not society. Phrenology was a graceless nineteent
century aberration. I could hear my friend Ann Druya
saying, 'The people we starve and torture have an unsociab
tendency to steal and murder. We think it's because the
brows overhang.' But the brains of murderers and savan
– the remains of Albert Einstein's brain are floating wan
in a bottle in Wichita – are indistinguishable. It is, ve
probably, society and not heredity that makes criminals

While scanning the collection amid such ruminations, my eye was caught by a label on one of the many low cylindrical bottles. I took the container from the shelf and examined it more closely. The label read *P. Broca*. In my hands was Broca's brain.

PAUL BROCA was a surgeon, a neurologist and an anthropologist, a major figure in the development of both medicine and anthropology in the mid-nineteenth century. He performed distinguished work on cancer pathology and the treatment of aneurisms, and made a landmark contribution to understanding the origins of aphasia – an impairment of the ability to articulate ideas. Broca was a brilliant and compassionate man. He was concerned with medical care for the poor. Under cover of darkness, at the risk of his own life, he successfully smuggled out of Paris in a horse-drawn cart 73 million francs, stuffed into carpetbags and hidden under potatoes, the treasury of the Assistance Publique which – he believed, at any rate – he was saving from pillage. He was the founder of modern brain surgery. He studied infant mortality. Towards the end of his career he was created a senator.

He loved, as one biographer said, mainly serenity and tolerance. In 1848 he founded a society of 'freethinkers'. Almost alone among French savants of the time, he was sympathetic to Charles Darwin's idea of evolution by natural selection. T. H. Huxley, 'Darwin's Bulldog', remarked that the mere mention of Broca's name filled him with a sense of gratitude, and Broca was quoted as saying, 'I would rather be a transformed ape than a degenerate son of Adam.' For these and other views he was publicly denounced for 'materialism' and, like Socrates, for corrupting the young. But he was made a senator nevertheless.

Earlier, Broca had encountered great difficulty in establishing a society of anthropology in France. The Minister of

Public Instruction and the Prefect of Police believed th anthropology must, as the free pursuit of knowledge abo human beings, be innately subversive to the state. Wh permission was at last and reluctantly granted for Broca talk about science with eighteen colleagues, the Prefect Police held Broca responsible personally for all that mig be said in such meetings 'against society, religion, or t government'. Even so, the study of human beings w considered so dangerous that a police spy in plain cloth was assigned to attend all meetings, with the understandi that authorization to meet would be withdrawn immediate if the spy was offended by anything that was said. In the circumstances the Society of Anthropology of Pa gathered for the first time on May 19, 1859, the year of t publication of *The Origin of Species*. In subsequent meetin an enormous range of subjects was discussed – archaeolog mythology, physiology, anatomy, medicine, psycholog linguistics and history – and it is easy to imagine the poli spy nodding off in the corner on many an occasion. One Broca related, the spy wished to take a small unauthoriz walk and asked if he might leave without anything threate ing to the state being said in his absence. 'No, no, my frien Broca responded. 'You must not go for a walk: sit down a earn your pay.' Not only the police but also the clergy oppos the development of anthropology in France, and in 18 the Roman Catholic political party organized a major cam paign against the teaching of the subject in the Anthr pological Institute of Paris founded by Broca.

Paul Broca died in 1880, perhaps of the very sort aneurism that he had studied so brilliantly. At the moment his death he was working on a comprehensive study of bra anatomy. He had established the first professional societie schools of research, and scientific journals of mode anthropology in France. His laboratory specimens becam incorporated into what for many years was called the Mus

Broca. Later it merged to become a part of the Musée de l'Homme.

It was Broca himself, whose brain I was cradling, who had established the macabre collection I had been contemplating. He had studied embryos and apes, and people of all races, measuring like mad in an effort to understand the nature of a human being. And despite the present appearance of the collection and my suspicions, he was not, at least by the standards of his time, more of a jingoist or a racist than most, and certainly not that standby of fiction and, more rarely, of fact: the cold, uncaring, dispassionate scientist, heedless of the human consequences of what he does. Broca very much cared.

In the *Revue d'Anthropologie* of 1880 there is a complete bibliography of Broca's writings. From the titles I could later glimpse something of the origins of the collection I had viewed: 'On the Cranium and Brain of the Assassin Lemaire', 'Presentation of the Brain of a Male Adult Gorilla', 'On the Brain of the Assassin Prévost', 'On the Supposed Heredity of Accidental Characteristics', 'The Intelligence of Animals and the Rule of Humans'. 'The Order of the Primates: Anatomical Parallels between Men and Apes', 'The Origin of the Art of Making Fire', 'On Double Monsters', 'Discussion on Microcephalics', 'Prehistoric Trepanning', 'On Two Cases of a Supernumerary Digit Developing at an Adult Age', 'The Heads of Two New Caledonians' and 'On the Skull of Dante Alighieri'. I did not know the present resting place of the cranium of the author of *The Divine Comedy*, but the collection of brains and skulls and heads that surrounded me clearly began in the work of Paul Broca.

BROCA WAS a superb brain anatomist and made important investigations of the limbic region, earlier called the rhinencephalon (the 'smell brain'), which we now know to be

profoundly involved in human emotion. But Broca is to
perhaps best known for his discovery of a small regio
the third convolution of the left frontal lobe of the cere
cortex, a region now known as Broca's area. Articu
speech, it turns out, as Broca inferred on only fragment
evidence, is to an important extent localized in and c
trolled by Broca's area. It was one of the first discoverie
a separation of function between the left and right he
spheres of the brain. But most important, it was one of
first indications that specific brain functions exist in p
ticular locales in the brain, that there is a connection betw
the anatomy of the brain and what the brain does, an acti
sometimes described as 'mind'.

Ralph Holloway is a physical anthropologist at Colum
University whose laboratory I imagine must bear so
resemblance to Broca's. Holloway makes rubber-latex ca
of the insides of skulls of human and related beings, past a
present, to attempt a reconstruction, from slight impressi
on the interior of the cranium, of what the brain must h
been like. Holloway believes that he can tell from a creatu
cranium whether Broca's area is present, and he has fou
evidence of an emerging Broca's area in the brain of *Ho*
habilis some two million years ago – just the time of
first constructions and the first tools. To this limited ext
there is something to the phrenological vision. It is v
plausible that human thought and industry went hand
hand with the development of articulate speech, and Bro
area may in a very real sense be one of the seats of
humanity, as well as a means for tracing our relationsh
with our ancestors on their way towards humanity.

And here was Broca's brain floating, in formalin and
fragments, before me. I could make out the limbic reg
which Broca had studied in others. I could see the c
volutions on the neocortex. I could even make out the gr
white left frontal lobe in which Broca's own Broca's a

esided, decaying and unnoticed, in a musty corner of a collection that Broca had himself begun.

It was difficult to hold Broca's brain without wondering whether in some sense Broca was still *in* there – his wit, his ceptical mien, his abrupt gesticulations when he talked, his quiet and sentimental moments. Might there be preserved in he configuration of neurons before me a recollection of the riumphant moment when he argued before the combined nedical faculties (and his father, overflowing with pride) on he origins of aphasia? A dinner with his friend Victor Hugo? A stroll on a moonlit autumn evening, his wife holding a pretty parasol, along the Quai Voltaire and the Pont Royal? Where do we go when we die? Is Paul Broca still here in his formalin-filled bottle? Perhaps the memory races have decayed, although there is good evidence from nodern brain investigations that a given memory is edundantly stored in many different places in the brain. Might it be possible at some future time, when neurophysiology has advanced substantially, to reconstruct the nemories or insights of someone long dead? And would that e a good thing? It would be the ultimate breach of privacy. But it would also be a kind of practical immortality, because, specially for a man like Broca, our minds are clearly a major spect of who we are.

From the character of this neglected storeroom in the Musée de l'Homme I had been ready to attribute to those who had assembled the collection – I had not known it was Broca at the time – a palpable sexism and racism and ingoism, a profound resistance to the idea of the relatedness of human beings and the other primates. And in part it was rue. Broca was a humanist of the nineteenth century, but nable to shake the consuming prejudices, the human social liseases, of his time. He thought men superior to women, nd whites superior to blacks. Even his conclusion that German brains were not significantly different from French

ones was in rebuttal to a Teutonic claim of Gallic inferiori
But he concluded that there were deep connections in bra
physiology between gorillas and men. Broca, the founder
a society of freethinkers in his youth, believed in the i
portance of untrammelled inquiry and had lived his life
pursuit of that aim. His falling short of these ideals sho
that someone as unstinting in the free pursuit of knowled
as Broca could still be deflected by endemic and respectab
bigotry. Society corrupts the best of us. It is a little unfai
think, to criticize a person for not sharing the enlightenme
of a later epoch, but it is also profoundly saddening th
such prejudices were so extremely pervasive. The questi
raises nagging uncertainties about which of the conventio
truths of our own age will be considered unforgivab
bigotry by the next. One way to repay Paul Broca for t
lesson which he has inadvertently provided us is to ch
lenge, deeply and seriously, our own most strongly he
beliefs.

These forgotten jars and their grisly contents had be
collected, at least partly, in a humanistic spirit; and perha
in some era of future advance in brain studies, they wou
prove useful once again. I would be interested in knowing
little more about the red-mustachioed man who had been,
part, returned to France from New Caledonia.

But the surroundings, the sense of a chamber of horro
evoked unbidden other unsettling thoughts. At the ve
least, we feel in such a place a pang of sympathy f
those – especially those who died young or in pain – who a
in so unseemly a way thus memorialized. Cannibals
northwestern New Guinea employ stacked skulls for doo
posts, and sometimes for lintels. Perhaps these are the mo
convenient building materials available, but the architec
cannot be entirely unaware of the terror that their constru
tions evoke in unsuspecting passers-by. Skulls have be
used by Hitler's SS, Hell's Angels, shamans, pirates, a

:ven those who label bottles of iodine, in a conscious effort o elicit terror. And it makes perfectly good sense. If I find nyself in a room filled with skulls, it is likely that there is omeone nearby, perhaps a pack of hyenas, perhaps some gaunt and dedicated decapitator, whose occupation or iobby it is to collect skulls. Such fellows are almost certainly o be avoided, or, if possible, killed. The prickle of the hairs on the back of my neck, the increased heartbeat and pulse ate, that strange, clammy feeling are designed by evolution o make me fight or flee. Those who avoid decapitation eave more offspring. Experiencing such fears bestows an :volutionary advantage. Finding yourself in a room full of rains is still more horrifying, as if some unspeakable moral nonster, armed with ghastly blades and scooping tools, were huffling and drooling somewhere in the attics of the Musée le l'Homme.

But all depends, I think, on the purpose of the collection. f its objective is to find out, if it has acquired human parts *ost mortem* – especially with the prior consent of those to vhom the parts once belonged – then little harm has been lone, and perhaps in the long run some significant human good. But I am not sure the scientists are entirely free of he motives of those New Guinea cannibals; are they not at east saying, 'I live with these heads every day. They don't ›other me. Why should *you* be so squeamish?'

LEONARDO AND VESALIUS were reduced to bribery and stealth n order to perform the first systematic dissections of uman beings in Europe, although there had been a flourishng and competent school of anatomy in ancient Greece. The first person to locate, on the basis of neuroanatomy, uman intelligence in the head was Herophilus of Chaledon, who flourished around 300 B.C. He was also the first o distinguish the motor from the sensory nerves, and performed the most thorough study of brain anatomy

attempted until the Renaissance. Undoubtedly there w
those who objected to his gruesome experimental predil
tions. There is a lurking fear, made explicit in the Fa
legend, that some things are not 'meant' to be known, t
some inquiries are too dangerous for human beings to ma
And in our own age, the development of nuclear weapo
may, if we are unlucky or unwise, turn out to be a case
precisely this sort. But in the case of experiments on
brain, our fears are less intellectual. They run deeper into
evolutionary past. They call up images of the wild bo
and highwaymen who would terrorize travellers and ru
populations in ancient Greece, by Procrustean mutilation
other savagery, until some hero – Theseus or Hercule
would effortlessly dispatch them. These fears have served
adaptive and useful function in the past. But I believe t
are mostly emotional baggage in the present. I was
terested, as a scientist who has written about the brain,
find such revulsions hiding in me, to be revealed for
inspection in Broca's collection. These fears are wo
fighting.

All inquiries carry with them some element of risk. Th
is no guarantee that the universe will conform to our p
dispositions. But I do not see how we can deal with
universe – both the outside and the inside universe – with
studying it. The best way to avoid abuses is for the popul
in general to be scientifically literate, to understand
implications of such investigations. In exchange for freed
of inquiry, scientists are obliged to explain their work
science is considered a closed priesthood, too difficult a
arcane for the average person to understand, the danger
abuse are greater. But if science is a topic of general inte
and concern – if both its delights and its social consequen
are discussed regularly and competently in the scho
the press, and at the dinner table – we have greatly impro
our prospects for learning how the world really is and

nproving both it and us. That is an idea, I sometimes fancy, nat may be sitting there still, sluggish with formalin, in Broca's brain.

CHAPTER 2

CAN WE KNOW THE UNIVERSE? REFLECTIONS ON A GRAIN OF SALT

* * *

Nothing is rich but the inexhaustible wealth
of nature. She shows us only surfaces,
but she is a million fathoms deep.

RALPH WALDO EMERSON

SCIENCE IS A WAY of thinking much more than it is a b
of knowledge. Its goal is to find out how the world wo
to seek what regularities there may be, to penetrate to
connections of things – from subnuclear particles, w
may be the constituents of all matter, to living organi
the human social community, and thence to the cosmos
whole. Our intuition is by no means an infallible guide.
perceptions may be distorted by training and prejudic
merely because of the limitations of our sense organs, wh
of course, perceive directly but a small fraction of
phenomena of the world. Even so straightforward a ques
as whether in the absence of friction a pound of lead
faster than a gram of fluff was answered incorrectly
Aristotle and almost everyone else before the time
Galileo. Science is based on experiment, on a willing
to challenge old dogma, on an openness to see the univ
as it really is. Accordingly, science sometimes requ
courage – at the very least the courage to question
conventional wisdom.

Beyond this the main trick of science is to *really* thin

omething: the shape of clouds and their occasional sharp ottom edges at the same altitude everywhere in the sky; the rmation of a dewdrop on a leaf; the origin of a name or a ord – Shakespeare, say, or 'philanthropic'; the reason for uman social customs – the incest taboo, for example; how it that a lens in sunlight can make paper burn; how a 'walking ick' got to look so much like a twig; why the Moon seems to llow us as we walk; what prevents us from digging a hole own to the centre of the Earth; what the definition is of lown' on a spherical Earth; how it is possible for the body convert yesterday's lunch into today's muscle and sinew; r how far is up – does the universe go on forever, or if it oes not, is there any meaning to the question of what lies on ie other side? Some of these questions are pretty easy. thers, especially the last, are mysteries to which no one ven today knows the answer. They are natural questions to sk. Every culture has posed such questions in one way or nother. Almost always the proposed answers are in the ature of 'Just So Stories', attempted explanations divorced om experiment, or even from careful comparative observaons.

But the scientific cast of mind examines the world critic-ly as if many alternative worlds might exist, as if other ings might be here which are not. Then we are forced to sk why what we see is present and not something else. Why e the Sun and the Moon and the planets spheres? Why not yramids, or cubes, or dodecahedra? Why not irregular, mbly shapes? Why so symmetrical, worlds? If you spend y time spinning hypotheses, checking to see whether they ake sense, whether they conform to what else we know, inking of tests you can pose to substantiate or deflate your ypotheses, you will find yourself doing science. And as you ome to practise this habit of thought more and more you ill get better and better at it. To penetrate into the heart f the thing – even a little thing, a blade of grass, as Walt

Whitman said – is to experience a kind of exhilaration th
it may be, only human beings of all the beings on this pla
can feel. We are an intelligent species and the use of
intelligence quite properly gives us pleasure. In this resp
the brain is like a muscle. When we think well, we feel go
Understanding is a kind of ecstasy.

But to what extent can we *really* know the universe arou
us? Sometimes this question is posed by people who hope
answer will be in the negative, who are fearful of a unive
in which everything might one day be known. And so
times we hear pronouncements from scientists who c
fidently state that everything worth knowing will soon
known – or even is already known – and who pa
pictures of a Dionysian or Polynesian age in which the
for intellectual discovery has withered, to be replaced b
kind of subdued languor, the lotus eaters drinking
mented coconut milk or some other mild hallucinogen.
addition to maligning both the Polynesians, who were
trepid explorers (and whose brief respite in paradise is n
sadly ending), as well as the inducements to intellect
discovery provided by some hallucinogens, this content
turns out to be trivially mistaken.

Let us approach a much more modest question:
whether we can know the universe or the Milky Way Gal
or a star or a world. Can we know, ultimately and
detail, a grain of salt? Consider one microgramme of ta
salt, a speck just barely large enough for someone with k
eyesight to make out without a microscope. In that grai
salt there are about 10^{16} sodium and chlorine atoms. T
is a 1 followed by 16 zeros, 10 million billion atoms. If
wish to know a grain of salt, we must know at least the th
dimensional positions of each of these atoms. (In fact, th
is much more to be known – for example, the nature of
forces between the atoms – but we are making only a mod
calculation.) Now, is this number more or less than

umber of things which the brain can know?

How much *can* the brain know? There are perhaps 10^{11} eurons in the brain, the circuit elements and switches that e responsible in their electrical and chemical activity for ie functioning of our minds. A typical brain neuron has erhaps a thousand little wires, called dendrites, which onnect it with its fellows. If, as seems likely, every bit of formation in the brain corresponds to one of these connec-ons, the total number of things knowable by the brain is o more than 10^{14}, one hundred trillion. But this number only one percent of the number of atoms in our speck f salt.

So in this sense the universe is intractable, astonishingly mune to any human attempt at full knowledge. We cannot n this level understand a grain of salt, much less the niverse.

But let us look a little more deeply at our microgramme f salt. Salt happens to be a crystal in which, except for efects in the structure of the crystal lattice, the position of very sodium and chlorine atom is predetermined. If we ould shrink ourselves into this crystalline world, we would e rank upon rank of atoms in an ordered array, a gularly alternating structure – sodium, chlorine, sodium, ilorine, specifying the sheet of atoms we are standing on id all the sheets above us and below us. An absolutely ure crystal of salt could have the position of every atom ecified by something like 10 bits of information.* This ould not strain the information-carrying capacity of the rain.

If the universe had natural laws that governed its

* Chlorine is a deadly poison gas employed on European battlefields in orld War I. Sodium is a corrosive metal which burns upon contact with ater. Together they make a placid and unpoisonous material, table salt. hy each of these substances has the properties it does is a subject called emistry, which requires more than 10 bits of information to understand.

behaviour to the same degree of regularity that determi
crystal of salt, then, of course, the universe would be kn
able. Even if there were many such laws, each of consi
able complexity, human beings might have the capabili
understand them all. Even if such knowledge exceeded
information-carrying capacity of the brain, we might s
the additional information outside our bodies – in bo
for example, or in computer memories – and still, in s
sense, know the universe.

Human beings are, understandably, highly motivate
find regularities, natural laws. The search for rules, the
possible way to understand such a vast and com
universe, is called science. The universe forces those who
in it to understand it. Those creatures who find every
experience a muddled jumble of events with no pre
ability, no regularity, are in grave peril. The universe bel
to those who, at least to some degree, have figured it

It is an astonishing fact that there *are* laws of nature, r
that summarize conveniently – not just qualitatively
quantitatively – how the world works. We might imagi
universe in which there are no such laws, in which the
elementary particles that make up a universe like our
behave with utter and uncompromising abandon. To un
stand such a universe we would need a brain at leas
massive as the universe. It seems unlikely that suc
universe could have life and intelligence, because beings
brains require some degree of internal stability and or
But even if in a much more random universe there
such beings with an intelligence much greater than our
there could not be much knowledge, passion or joy.

Fortunately for us, we live in a universe that has at l
important parts that are knowable. Our common-s
experience and our evolutionary history have prepared u
understand something of the workaday world. When w
into other realms, however, common sense and ordi

ıtuition turn out to be highly unreliable guides. It is .unning that as we go close to the speed of light our mass ıcreases indefinitely, we shrink towards zero thickness in ıe direction of motion, and time for us comes as near to ıopping as we would like. Many people think that this is ılly, and every week or two I get a letter from someone /ho complains to me about it. But it is a virtually certain onsequence not just of experiment but also of Albert :instein's brilliant analysis of space and time called the pecial Theory of Relativity. It does not matter that these ffects seem unreasonable to us. We are not in the habit f travelling close to the speed of light. The testimony of our ommon sense is suspect at high velocities.

Or consider an isolated molecule composed of two atoms haped something like a dumbbell – a molecule of salt, it ıight be. Such a molecule rotates about an axis through ıe line connecting the two atoms. But in the world of quan- ım mechanics, the realm of the very small, not all orienta- ons of our dumbbell molecule are possible. It might be hat the molecule could be oriented in a horizontal position, ay, or in a vertical position, but not at many angles in etween. Some rotational positions are forbidden. For- idden by what? By the laws of nature. The universe is uilt in such a way as to limit, or quantize, rotation. We o not experience this directly in everyday life; we would nd it startling as well as awkward in sitting-up exercises, ɔ find arms outstretched from the sides or pointed up to he skies permitted but many intermediate positions for- idden. We do not live in the world of the small, on the cale of 10^{-13} centimetres, in the realm where there are welve zeros between the decimal place and the one. Our ommon-sense intuitions do not count. What does count is xperiment – in this case observations from the far infrared pectra of molecules. They show molecular rotation to be uantized.

The idea that the world places restrictions on w humans might do is frustrating. Why *shouldn't* we be abl have intermediate rotational positions? Why *can't* we tra faster than the speed of light? But so far as we can tell, t is the way the universe is constructed. Such prohibitions only press us towards a little humility; they also make world more knowable. Every restriction corresponds t law of nature, a regularization of the universe. The m restrictions there are on what matter and energy can do, more knowledge human beings can attain. Whether in so sense the universe is ultimately knowable depends not o on how many natural laws there are that encompass wid divergent phenomena, but also on whether we have openness and the intellectual capacity to understand su laws. Our formulations of the regularities of nature surely dependent on how the brain is built, but also, and t significant degree, on how the universe is built.

For myself, I like a universe that includes much that unknown and, at the same time, much that is knowable. universe in which everything is known would be static a dull, as boring as the heaven of some weak-minded theo gians. A universe that is unknowable is no fit place fo thinking being. The ideal universe for us is one very mu like the universe we inhabit. And I would guess that this not really much of a coincidence.

CHAPTER 3

THAT WORLD WHICH BECKONS LIKE A LIBERATION

* * *

To punish me for my contempt for authority,
Fate made me an authority myself.

EINSTEIN

LBERT EINSTEIN was born in Ulm, Germany, in 1879, just century ago. He is one of the small group of people in ny epoch who remake the world through a special gift, a alent for perceiving old things in new ways, for posing eep challenges to conventional wisdom. For many decades e was a saintly and honoured figure, the only scientist the verage person could readily name. In part because of his cientific accomplishments, at least dimly grasped by the ublic; in part because of his courageous positions on social ssues; and in part because of his benign personality, Einstein vas admired and revered throughout the world. For scien-fically inclined children of immigrant parents, or those rowing up in the Depression, like me, the reverence ccorded Einstein demonstrated that there were such people s scientists, that a scientific career might not be totally eyond hope. One major function he involuntarily served vas as a scientific role model. Without Einstein, many of the oung people who became scientists after 1920 might never ave heard of the existence of the scientific enterprise. The ogic behind Einstein's Special Theory of Relativity could ave been developed a century earlier, but, although there vere some premonitory insights by others, relativity had to

wait for Einstein. Yet fundamentally the physics of spe
relativity is very simple, and many of the essential res
can be derived from high school algebra and ponderin
boat paddling upstream and downstream. Einstein's life
rich in genius and irony, a passion for the issues of his ti
insights into education, the connection between science
politics, and was a demonstration that individuals can, a
all, change the world.

As a child Einstein gave little indication of what was
come. 'My parents,' he recalled later, 'were worried becau
started to talk comparatively late, and they consulted
doctor because of it ... I was at that time ... certainly
younger than three.' He was an indifferent student
elementary school, where he said the teachers reminded h
of drill sergeants. In Einstein's youth, a bomba
nationalism and intellectual rigidity were the hallmarks
European education. He rebelled against the dull, mech
ized methods of teaching. 'I preferred to endure all sorts
punishment rather than learn to gabble by rote.' Einst
was always to detest rigid disciplinarians, in education
science and in politics.

At five he was stirred by the mystery of a compass. A
he later wrote, 'at the age of 12 I experienced a secc
wonder of a totally different nature in a little book deal
with Euclidean plane geometry.... Here were assertions
for example the intersection of the three altitudes o
triangle in one point, which – though by no means evid
– could nevertheless be proved with such certainty that a
doubt appeared to be out of the question. This lucidity a
certainty made an indescribable impression upon m
Formal schooling provided only a tedious interruption
such contemplations. Einstein wrote of his self-educati
'At the age of 12 to 16 I familiarized myself with
elements of mathematics together with the principles
differential and integral calculus. In doing so I had

good fortune of finding books which were not too particular in their logical rigour, but which made up for this by permitting the main thoughts to stand out clearly and synoptically ... I also had the good fortune of getting to know the essential results and methods of the entire field of the natural sciences in an excellent popular exposition, which limited itself almost throughout to qualitative aspects .. a work which I read with breathless attention.' Modern popularizers of science may take some comfort from these words.

Not one of his teachers seems to have recognized his talents. At the Munich *Gymnasium*, the city's leading secondary school, one of the teachers told him, 'You'll never amount to anything, Einstein.' At age fifteen it was strongly suggested that he leave school. The teacher observed, 'Your very presence spoils the respect of the class for me.' He accepted this suggestion with gusto and spent many months wandering through northern Italy, a high school dropout in the 1890s. Throughout his life he preferred informal dress and manner. Had he been a teen-ager in the 1960s or 1970s rather than the 1890s, conventional people would almost certainly have called him a hippie.

Yet his curiosity about physics and his wonder about the natural universe soon overcame his distaste for formal education, and he found himself applying, with no high school diploma, to the Federal Institute of Technology in Zurich, Switzerland. He failed the entrance examination, enrolled himself in a Swiss high school to satisfy his deficiencies, and was admitted to the Federal Institute the following year. But he was still a mediocre student. He resented the prescribed curriculum, avoided the lecture room and tried to pursue his true interests. He later wrote: 'The hitch in this was, of course, the fact that you had to cram all this stuff into your mind for the examination, whether you liked it or not.'

He managed to graduate only because his close fri
Marcel Grossmann assiduously attended classes and sha
his notes with Einstein. On Grossmann's death many ye
later, Einstein wrote: 'I remember our student days. He
irreproachable student, I myself disorderly and a dream
He, on good terms with the teachers and understand
everything; I a pariah, discontented and little loved ... T
the end of our studies – I was suddenly abandoned
everyone, standing at a loss on the threshold of life.' By
mersing himself in Grossmann's notes, he managed
graduate from college. But, he recalled, studying for the fi
examinations 'had such a deterring effect on me that .
found the consideration of any scientific problem distaste
to me for an entire year.... It is little short of a mira
that modern methods of instruction have not already co
pletely strangled the holy curiosity of inquiry, because w
this delicate little plant needs most, apart from ini
stimulation, is freedom; without that it is surely destroyed
I believe that one could even deprive a healthy beast
prey of its voraciousness, if one could force it with a w
to eat continuously whether it were hungry or not ...'
remarks should be sobering to those of us engaged
higher education in science. I wonder how many poten
Einsteins have been permanently discouraged throu
competitive examinations and the forced feeding of c
ricula.

After supporting himself with odd jobs, and being pass
over for positions he considered desirable, Einstein accep
an offer as an examiner of applications at the Swiss Pat
Office in Berne, an opportunity made available through
intervention of Marcel Grossmann's father. About the sa
time he rejected his German nationality and became a Sw
citizen. Three years later, in 1903, he married his coll
sweetheart. Almost nothing is known about which pat
applications Einstein approved and which he rejected.

would be interesting to know whether any of the proposed patents stimulated his thinking in physics.

One of his biographers, Banesh Hoffman, writes that at the Patent Office, Einstein 'soon learned to do his chores efficiently and this let him snatch precious morsels of time for his own surreptitious calculations, which he guiltily hid in a drawer when footsteps approached.' Such were the circumstances attending the birth of the great relativity theory. But Einstein later nostalgically recalled the Patent Office as 'that secular cloister where I hatched my most beautiful ideas.'

On several occasions he was to suggest to colleagues that the occupation of lighthouse keeper would be a suitable position for a scientist – because the work would be comparatively easy and would allow the contemplation necessary to do scientific research. 'For Einstein,' said his collaborator Leopold Infeld, 'loneliness, life in a lighthouse, would be most stimulating, would free him from so many of the duties which he hates. In fact it would be for him the ideal life. But nearly every scientist thinks just the opposite. It was the curse of *my* life that for a long time I was not in a scientific atmosphere, that I had no one with whom to talk physics.'

Einstein also believed that there was something dishonest about making money by teaching physics. He argued that it was far better for a physicist to support himself by some other simple and honest labour, and do physics in his spare time. When making a similar remark many years later in America, Einstein mused that he would have liked to be a plumber, and was promptly awarded honorary membership in the plumbers' union.

In 1905 Einstein published four research papers, the product of his spare time at the Swiss Patent Office, in the leading physics journal of the time, the *Annalen der Physik*. The first demonstrated that light has particle as well as wave

properties, and explained the previously baffling phe
electric effect in which electrons are emitted by solids wi
irradiated by light. The second explored the nature
molecules by explaining the statistical 'Brownian moti
of suspended small particles. And the third and fou
introduced the Special Theory of Relativity and for the f
time expressed the famous equation, $E = mc^2$, which is
widely quoted and so rarely understood.

The equation expresses the convertibility of matter i
energy, and vice versa. It extends the law of the conservat
of energy into a law of conservation of energy and m
stating that energy and mass can be neither created
destroyed – although one form of energy or matter can
converted into another form. In the equation, E stands
the energy equivalent of the mass m. The amount of ene
that could, under ideal circumstances, be extracted fro
mass is mc^2, where c is the velocity of light = 30 bill
centimetres per second. (The velocity of light is alw
written as lower-case c, never as upper-case.) If we meas
m in grammes and c in centimetres per second,, E
measured in a unit of energy called ergs. The complete c
version of one gramme of mass into energy thus relea
$1 \times (3 \times 10^{10})^2 = 9 \times 10^{20}$ ergs, which is the equivalen
the explosion of roughly a thousand tons of TNT. T
enormous energy resources are contained in tiny amount
matter, if only we knew how to extract the energy. Nucl
weapons and nuclear power plants are common terrest
examples of our halting and ethically ambiguous effort
extract the energy that Einstein showed was present in
manner. A thermonuclear weapon, a hydrogen bomb,
device of terrifying power – but even it is capable
extracting less than one percent of mc^2 from a mass m
hydrogen.

Einstein's four papers published in 1905 would have b
an impressive output for the full-time research work c

hysicist over a lifetime; for the spare-time work of a wenty-six-year-old Swiss patent clerk in a single year it is othing short of astonishing. Many historians of science ave called 1905 the *Annus Mirabilis*, the miracle year. here had been, with uncanny resemblances, only one revious such year in the history of physics – 1666, when saac Newton, aged twenty-four, in enforced rural isolation ecause of an epidemic of bubonic plague) produced an xplanation for the spectral nature of sunlight, invented ifferential and integral calculus, and devised the universal heory of gravitation. Together with the General Theory f Relativity, first formulated in 1915, the 1905 papers epresent the principal output of Einstein's scientific life.

Before Einstein, it was widely held by physicists that there ere privileged frames of reference, such things as absolute pace and absolute time. Einstein's starting point was that ll frames of reference – all observers, no matter what their ocale, velocity or acceleration – would see the fundamental aws of nature in the same way. It seems likely that instein's view on frames of reference was influenced by his ocial and political attitudes and his resistance to the strident ngoism he found in late-nineteenth-century Germany. ndeed, in this sense the idea of relativity has become an nthropological commonplace, and social scientists have dopted the idea of cultural relativism: there are many ifferent social contexts and world views, ethical and eligious precepts, expressed by various human societies, nd most of comparable validity.

Special relativity was at first by no means widely accepted. ttempting once again to break into an academic career, instein submitted his already published relativity paper to erne University as an example of his work. He evidently onsidered it a significant piece of research. It was rejected as ncomprehensible, and he was to remain at the Patent ffice until 1909. But his published work did not go un-

noticed, and it slowly began to dawn on a few
leading European physicists that Einstein might well
of the greatest scientists of all time. Still, his wo
relativity remained highly controversial. In a letter of r
mendation for Einstein for a position at the Univers
Berlin, a leading German scientist suggested that rela
was a hypothetical excursion, a momentary aberration
that, despite it, Einstein really *was* a first-rate thinker.
Nobel Prize, which he learned about during a visit t
Orient in 1921, was awarded for his paper on the p
electric effect and 'other contributions' to theore
physics. Relativity was still considered too controversi
be mentioned explicitly.)

Einstein's views on religion and politics were conne
His parents were of Jewish origin, but they did not ob
religious ritual. Nevertheless, Einstein came to a con
tional religiosity 'by way of the traditional educa
machine, the State and the schools.' But at age twelve
came to an abrupt end: 'Through the reading of pop
scientific books I soon reached the conviction that n
of the stories of the Bible could not be true. The
sequence was a positively fanatic free thinking cou
with the impression that youth is intentionally b
deceived by the State through lies; it was a crushing
pression. Suspicion against every kind of authority
out of this experience, a sceptical attitude attitude tow
the convictions which were alive in any specific social
vironment – an attitude which has never again left me,
though later on, because of a better insight into the ca
connections, it lost some of its original poignancy.'

Just before the outbreak of World War I, Eins
accepted a professorship at the well-known Kaiser Wilh
Institute in Berlin. The desire to be at the leading ce
of theoretical physics was momentarily stronger than
antipathy to German militarism. The outbreak of W

War I caught Einstein's wife and two sons in Switzerland, unable to return to Germany. A few years later this enforced separation led to divorce, but on receiving the Nobel Prize in 1921, Einstein, although since remarried, donated the full $30,000 to his first wife and their children. His eldest son later became a significant figure in civil engineering, holding a professorship at the University of California, but his second son, who idolized his father, accused him – in later years, and to Einstein's great anguish – of having ignored him during his youth.

Einstein, who described himself as a socialist, became convinced that World War I was largely the result of the scheming and incompetence of 'the ruling classes', a conclusion with which many contemporary historians agree. He became a pacifist. When other German scientists enthusiastically supported their nation's military enterprises, Einstein publicly condemned the war as 'an epidemic delusion'. Only his Swiss citizenship prevented him from being imprisoned, as indeed happened to his friend the philosopher Bertrand Russell in England at the same time and for the same reason. Einstein's views on the war did not increase his popularity in Germany.

However, the war did, indirectly, play a role in making Einstein's name a household word. In his General Theory of Relativity Einstein explored the proposition – an idea still astonishing in its simplicity, beauty and power – that the gravitational attraction between two masses comes about by those masses distorting or bending ordinary Euclidean space nearby. The quantitative theory reproduced, to the accuracy to which it had been tested, Newton's law of universal gravitation. But in the next decimal place, so to speak, general relativity predicted significant differences from Newton's views. This is in the classic tradition of science, in which new theories retain the established results of the old but make a set of new

predictions which permits a decisive distinction to be draw between the two outlooks.

The three tests of general relativity that Einstein propose concerned anomalies in the motion of the orbit of th planet Mercury, the red shifts in the spectral lines of ligh emitted by a massive star, and the deflection of starlig near the Sun. Before the Armistice was signed in 191 British expeditions were mustered to Brazil and to the islan of Principe off West Africa to observe, during a total eclip of the Sun, whether the deflection of starlight was in accor with the predictions of general relativity. It was. Einstein views were vindicated; and the symbolism of a Britis expedition confirming the work of a German scientist whe the two countries were still technically at war appealed to th better instincts of the public.

But at the same time, a well-financed public campaig against Einstein was launched in Germany. Mass meetin with anti-Semitic overtones were staged in Berlin and els where to denounce the relativity theory. Einstein's co leagues were shocked, but most of them, too timid f politics, did nothing to counter it. With the rise of th Nazis in the 1920s and early 1930s, Einstein, against h natural inclination for a life of quiet contemplation, foun himself speaking up – courageously and often. He testifie in German courts on behalf of academics on trial for the political views. He appealed for amnesty for politic prisoners in Germany and abroad (including Sacco an Vanzetti and the Scottsboro 'boys' in the United States When Hitler became chancellor in 1933, Einstein and h second wife fled Germany.

The Nazis burned Einstein's scientific works, along wi other books by anti-Fascist authors, in public bonfires. A all-out assault was launched on Einstein's scientific statur Leading the attack was the Nobel laureate physicist Philip Lenard, who denounced what he called the 'mathematical

otched-up theories of Einstein' and the 'Asiatic spirit in cience'. He went on: 'Our Führer has eliminated this same pirit in politics and national economy, where it is known as arxism. In natural science, however, with the over-mphasis on Einstein, it still holds sway. We must recognize at it is unworthy of a German to be the intellectual llower of a Jew. Natural science, properly so-called, is of mpletely aryan origin ... *Heil Hitler!*'

Many Nazi scholars joined in warning against the 'Jewish' id 'Bolshevik' physics of Einstein. Ironically, in the Soviet nion at about the same time, prominent Stalinist intellec-als were denouncing relativity as 'bourgeois physics'. 'hether or not the *substance* of the theory being attacked as correct was, of course, never considered in such liberations.

Einstein's identification of himself as a Jew, despite his ofound estrangement from traditional religions, was due ntirely to the upsurge of anti-Semitism in Germany in the 20s. For this reason he also became a Zionist. But cording to his biographer Philipp Frank, not all Zionist oups welcomed him, because he demanded that the Jews ake an effort to befriend the Arabs and to understand their ay of life – a devotion to cultural relativism made more pressive by the difficult emotional issues involved. How-er, he continued to support Zionism, particularly as the creasing desperation of European Jews became known in e late 1930s. (In 1948 Einstein was offered the presidency f Israel, but politely declined. It is interesting to speculate hat differences in the politics of the Near East, if any, ight have been produced by Albert Einstein as the resident of Israel.)

After leaving Germany, Einstein learned that the Nazis id placed a price of 20,000 marks on his head. ('I didn't now it was worth so much.') He accepted an appointment the recently founded Institute for Advanced Study in

Princeton, New Jersey, where he was to remain for t
of his life. When asked what salary he thought f
suggested $3,000. Seeing a look of astonishment pa
the face of the representative of the Institute, he cor
he had proposed too much and mentioned a smaller a
His salary was set at $16,000, a goodly sum for the

Einstein's prestige was so high that it was natural fo
émigré European physicists in the United States to ap
him in 1939 to write a letter to President Franl
Roosevelt, proposing the development of an atomic b
outstrip a likely German effort to acquire nuclear we
Although Einstein had not been working in nuclear p
and later played no role in the Manhattan Project, he
the initial letter that led to the establishment of the M
tan Project. It is likely, however, that the bomb woul
been developed by the United States regardless of Ei
urging. Even without $E = mc^2$, the discovery of
activity by Antoine Becquerel and the investigation
atomic nucleus by Ernest Rutherford – both done e
independently of Einstein – would very likely have le
development of nuclear weapons. Einstein's dread o
Germany had long since caused him to abandon, alt
with considerable pain, his pacifist views. But when
transpired that the Nazis had been unable to develop n
weapons, Einstein expressed remorse: 'Had I known t
Germans would not succeed in developing an atomic
I would have done nothing for the bomb.'

In 1945 Einstein urged the United States to bre
relations with Franco Spain, which had supported the
in World War II. John Rankin, a conservative congre
from Mississippi, attacked Einstein in a speech to the
of Representatives, declaring that 'this foreign-born a
would have us plunge into another war in order to f
the spread of Communism throughout the world .
about time the American people got wise to Einstei

Einstein was a powerful defender of civil liberties in the nited States during the darkest period of McCarthyism in e late 1940s and early 1950s. Watching the rising tide of steria, he had the disturbing feeling that he had seen mething similar in Germany in the 1930s. He urged fendants to refuse to testify before the House Un-merican Activities Committee, saying that every person ould be 'prepared for jail and economic ruin ... for the crifice of his personal welfare in the interest of ... his untry.' He held that there was 'a duty in refusing to operate in any undertaking that violates the Constitu-nal rights of the individual. This holds in particular for inquisitions that are concerned with the private life and e political affiliations of the citizens ...' For taking this sition, Einstein was widely attacked in the press. And nator Joseph McCarthy stated in 1953 that anyone who offered such advice was 'himself an enemy of America'. In s later years it became fashionable in some circles to couple acknowledgment of Einstein's scientific genius with a tronizing dismissal of his political views as 'naïve'. But nes have changed. I wonder if it is not more reasonable argue in quite a different direction: in a field such as ysics, where ideas can be quantified and tested with great ecision, Einstein's insights stand unrivalled, and we are tonished that he could see so clearly where others were st in confusion. Is it not worth considering that in the much rkier field of politics his insights might also have some ndamental validity?

In his Princeton years Einstein's passion remained, as ways, the life of the mind. He worked long and hard on a nified Field Theory which would combine gravitation, ctricity and magnetism on a common basis, but his empt is widely considered to have been unsuccessful. He ed to see his General Theory of Relativity incorporated the principal tool for understanding the large-scale struc-

ture and evolution of the universe, and would have b
delighted to witness the vigorous application of gen
relativity occurring in astrophysics today. He never un
stood the reverence with which he was held, and inc
complained that his colleagues and Princeton gradu
students would not drop in on him unannounced for fea
disturbing him.

But he wrote: 'My passionate interest in social justice
social responsibility has always stood in curious contras
a marked lack of desire for direct association with men
women. I am a horse for single harness, not cut out
tandem or team work. I have never belonged wholehearte
to country or State, to my circle of friends or even to
own family. These ties have always been accompanied
a vague aloofness, and the wish to withdraw into my
increases with the years. Such isolation is sometimes bi
but I do not regret being cut off from the understand
and sympathy of other men. I lose something by it, to
sure, but I am compensated for it in being rendered
dependent of the customs, opinions and prejudices of ot
and am not tempted to rest my peace of mind upon s
shifting foundations.'

His principal recreations throughout his life were play
the violin and sailing. In these years Einstein looked
and in some respects was a sort of aging hippie. He let
white hair grow long and preferred sweaters and a lea
jacket to a suit and tie, even when entertaining fam
visitors. He was utterly without pretence and, with no af
tation, explained that 'I speak to everyone in the same w
whether he is the garbage man or the President of
University.' He was often available to the public, someti
being willing to help high school students with t
geometry problems – not always successfully. In the
scientific tradition he was open to new ideas but requ
that they pass rigorous standards of evidence. He was o

minded but sceptical about claims of planetary catastrophism in recent Earth history and about experiments alleging extrasensory perception, his reservations about the latter stemming from contentions that purported telepathic abilities do not decline with increasing distance between sender and receiver.

In matters of religion, Einstein thought more deeply than many others and was repeatedly misunderstood. On the occasion of Einstein's first visit to America, Cardinal O'Connell of Boston warned that the relativity theory 'cloaked the ghastly apparition of atheism'. This alarmed a New York rabbi who cabled Einstein: 'Do you believe in God?' Einstein cabled back: 'I believe in Spinoza's God, who revealed himself in the harmony of all being, not in the God who concerns himself with the fate and actions of men' – a more subtle religious view embraced by many theologians today. Einstein's religious beliefs were very genuine. In the 1920s and 1930s he expressed grave doubts about a basic precept of quantum mechanics: that at the most fundamental level of matter, particles behave in an unpredictable way, as expressed by the Heisenberg uncertainty principle. Einstein said, 'God does not play dice with the cosmos.' And on another occasion he asserted, 'God is subtle, but he is not malicious.' In fact, Einstein was so fond of such aphorisms that the Danish physicist Niels Bohr turned to him on one occasion and with some exasperation said, 'Stop telling God what to do.' But there were many physicists who felt that if anyone knew God's intentions, it was Einstein.

One of the foundations of special relativity is the precept that no material object can travel as fast as light. This light barrier has proved annoying to many people who wish there to be no constraints on what human beings might ultimately do. But the light limit permits us to understand much of the world that was previously mysterious in a simple

and elegant way. However, where Einstein taketh away also giveth. There are several consequences of spe relativity that seem counterintuitive, contrary to our ev day experience, but that emerge in a detectable fashion w we travel close to the speed of light – a regime of velo in which common sense has had little experience (Cha 2). One of these consequences is that as we travel sufficie close to the speed of light, time slows down – our w watches, our atomic clocks, our biological aging. Thu space vehicle travelling very close to the speed of light co travel between any two places, no matter how distant, in conveniently short period of time – as measured on bo the spacecraft, but not as measured on the launch plan We might therefore one day travel to the centre of Milky Way Galaxy and return in a time of a few deca measured on board the ship – although, as measured b on Earth, the elapsed time would be sixty thousand ye and very few of the friends who saw us off would around to commemorate our return. A vague recogni of this time dilation was made in the motion picture *C Encounters of the Third Kind*, although a gratuitous opin was then injected that Einstein was probably an ex terrestrial. His insights were stunning, to be sure, but was very human, and his life stands as an example of wh if they are sufficiently talented and courageous, hum beings can accomplish.

EINSTEIN'S LAST public act was to join with Bertrand Rus and many other scientists and scholars in an unsucces attempt to bring about a ban on the development of nuc weapons. He argued that nuclear weapons had chan everything except our way of thinking. In a world divi into hostile states he viewed nuclear energy as the grea menace to the survival of the human race. 'We have choice,' he said, 'to outlaw nuclear weapons or face gen

nnihilation.... Nationalism is an infantile disease. It is the ıeasles of mankind ... Our schoolbooks glorify war and ide its horrors. They inculcate hatred in the veins of hildren. I would teach peace rather than war. I would ıculcate love rather than hate.'

At age sixty-seven, nine years before his death in 1955, Einstein described his lifelong quest: 'Out yonder there was his huge world, which exists independently of us human eings and which stands before us like a great, eternal riddle, t least partially accessible to our inspection and thinking. The contemplation of this world beckoned like a liberation .. The road to this paradise was not so comfortable and lluring as the road to the religious paradise; but it has roved itself as trustworthy, and I have never regretted aving chosen it.'

CHAPTER 4

IN PRAISE OF SCIENCE AND TECHNOLOGY

* * *

The cultivation of the mind
is a kind of food supplied for the soul of man.

MARCUS TULLIUS CICERO,
De Finibus Bonorum et Malorum, Vol. 19 (45–44 B.C.)

To one, science is an exalted goddess;
to another it is a cow which provides him with butter.

FRIEDRICH VON SCHILLER,
Xenien (1796)

IN THE MIDDLE of the nineteenth century, the largely
educated British physicist Michael Faraday was visited
his monarch, Queen Victoria. Among Faraday's m
celebrated discoveries, some of obvious and immed
practical benefit, were more arcane findings in electri
and magnetism, then little more than laboratory curiosi
In the traditional dialogue between heads of state and he
of laboratories, the Queen asked Faraday of what use s
studies were, to which he is said to have replied, 'Mad
of what use is a baby?' Faraday had an idea that t
might someday be something practical in electricity
magnetism.

In the same period the Scottish physicist James C
Maxwell set down four mathematical equations, based
the work of Faraday and his experimental predecess
relating electrical charges and currents with electric

agnetic fields. The equations exhibited a curious lack of mmetry, and this bothered Maxwell. There was something naesthetic about the equations as then known, and to nprove the symmetry Maxwell proposed that one of the quations should have an additional term, which he called ie displacement current. His argument was fundamentally ituitive; there was certainly no experimental evidence or such a current. Maxwell's proposal had astonishing onsequences. The corrected Maxwell equations implied ie existence of electromagnetic radiation, encompassing amma rays, X-rays, ultraviolet light, visible light, infrared id radio. They stimulated Einstein to discover Special elativity. Faraday and Maxwell's laboratory and theoreti-l work together have led, one century later, to a technical volution on the planet Earth. Electric lights, telephones, ionographs, radio, television, refrigerated trains making esh produce available far from the farm, cardiac pace-akers, hydroelectric power plants, automatic fire alarms id sprinkler systems, electric trolleys and subways, and e electronic computer are a few devices in the direct evolu-onary line from the arcane laboratory puttering of Faraday id the aesthetic dissatisfaction of Maxwell, staring at some athematical squiggles on a piece of paper. Many of the ost practical applications of science have been made in is serendipitous and unpredictable way. No amount of oney would have sufficed in Victoria's day for the leading ientists in Britain to have simply sat down and invented, us say, television. Few would argue that the net effect these inventions was other than positive. I notice that en many young people who are profoundly disenchanted ith Western technological civilization, often for good ason, still retain a passionate fondness for certain aspects high technology – for example, high-fidelity electronic usic systems.

Some of these inventions have fundamentally changed the

character of our global society. Ease of communication deprovincialized many parts of the world, but cult diversity has been likewise diminished. The practical ad tages of these inventions are recognized in virtually human societies; it is remarkable how infrequently emer nations are concerned with the negative effects of technology (environmental pollution, for example); have clearly decided that the benefits outweigh the ri One of Lenin's aphorisms was that socialism plus electrif tion equals communism. But there has been no m vigorous or inventive pursuit of high technology than in West. The resulting rate of change has been so rapid many of us find it difficult to keep up. There are m people alive today who were born before the first airpl and have lived to see Viking land on Mars, and Pioneer the first interstellar spacecraft, be ejected from the s system, or who were raised in a sexual code of Victo severity and now find themselves immersed in substan sexual freedom, brought about by the widespread av ability of effective contraceptives. The rate of change been disorienting for many, and it is easy to understand nostalgic appeal of a return to an earlier and sim existence.

But the standard of living and conditions of work for great bulk of the population in, say, Victorian Engla were degrading and demoralizing compared to indust societies today, and the life-expectancy and infant-morta statistics were appalling. Science and technology may b part responsible for many of the problems that face today – but largely because public understanding of t is desperately inadequate (technology is a tool, no panacea), and because insufficient effort has been mad accommodate our society to the new technologies. Consi ing these facts, I find it remarkable that we have don well as we have. Luddite alternatives can solve noth

More than one billion people alive today owe the margin between barely adequate nutrition and starvation to high agricultural technology. Probably an equal number have survived, or avoided disfiguring, crippling or killing diseases because of high medical technology. Were high technology to be abandoned, these people would also be abandoned. Science and technology may be the cause of some of our problems, but they are certainly an essential element in any foreseeable solution to those same problems – both nationally and planetwide.

I do not think that science and technology have been pursued as effectively, with as much attention to their ultimate humane objectives and with as adequate a public understanding as, with a little greater effort, could have been accomplished. It has, for example, gradually dawned on us that human activities can have an adverse effect on not only the local but also the global environment. By accident a few research groups in atmospheric photochemistry discovered that halocarbon propellants from aerosol spray cans will reside for very long periods in the atmosphere, circulate to the stratosphere, partially destroy the ozone there, and let ultraviolet light from the sun leak down to the Earth's surface. Increased skin cancer for whites was the most widely advertised consequence (blacks are greatly adapted to increased ultraviolet flux). But very little public attention has been given to the much more serious possibility that microorganisms, occupying the base of an elaborate food pyramid at the top of which is *Homo sapiens*, might also be destroyed by the increased ultraviolet light. Steps have finally, although reluctantly, been taken to ban halocarbons from spray cans (although no one seems to be worrying about the same molecules used in refrigerators) and as a result the immediate dangers are probably slight. What I find most worrisome about this incident is how accidental was the discovery that the problem existed at all.

One group approached this problem because it had writ the appropriate computer programs, but in quite a differ context: they were concerned with the chemistry of atmosphere of the planet Venus, which contains hyd chloric and hydrofluoric acids. The need for a broad a diverse set of research teams, working on a great variety problems in pure science, is clearly required for our c tinued survival. But what other problems, even more sev exist which we do not know about because no resea group happens as yet to have stumbled on them? For e problem we have uncovered, such as the effect of haloc bons on the ozonosphere, might there not be another do lurking around the corner? It is therefore an astonish fact that nowhere in the federal government, major univer ties or private research institutes is there a single hig competent, broadly empowered and adequately fun research group whose function it is to seek out and def future catastrophes resulting from the development of n technologies.

The establishment of such research and environmen assessment organizations will require substantial politi courage if they are to be effective at all. Technologi societies have a tightly knit industrial ecology, an interwo network of economic assumptions. It is very difficult challenge one thread in the network without causing trem in all. Any judgment that a technological development have adverse human consequences implies a loss of pr for someone. The DuPont Comany, the principal ma facturers of halocarbon propellants, for example, took curious position in public debates that all conclusions ab halocarbons destroying the ozonosphere were 'theoretic They seemed to be implying that they would be prepa to stop halocarbon manufacture only after the conclusi were tested experimentally – that is, when the ozonosph was destroyed. There are some problems where inferen

idence is all that we will have; where once the catastrophe rives it is too late to deal with it.

Similarly, the new Department of Energy can be effective ly if it can maintain a distance from vested commercial erests, if it is free to pursue new options even if such tions imply loss of profits for selected industries. The same clearly true in pharmaceutical research, in the pursuit of ernatives to the internal-combustion engine, and in many her technological frontiers. I do not think that the velopment of new technologies should be placed in the ntrol of old technologies; the temptation to suppress the mpetition is too great. If we Americans live in a free-terprise society, let us see substantial independent enter-ise in all of the technologies upon which our future may pend. If organizations devoted to technological innova-n and its boundaries of acceptability are not challenging nd perhaps even offending) at least *some* powerful groups, ey are not accomplishing their purpose.

There are many practical technological developments that e not being pursued for lack of government support. For ample, as agonizing a disease as cancer is, I do not think it n be said that our civilization is threatened by it. Were ncer to be cured completely, the average life expectancy uld be extended by only a few years, until some other ease – which does not now have its chance at cancer tims – takes over. But a very plausible case can be de that our civilization is fundamentally threatened by e lack of adequate fertility control. Exponential increases population will dominate any arithmetic increases, even ose brought about by heroic technological initiatives, in e availability of food and resources, as Malthus long ago alized. While some industrial nations have approached ro population growth, this is not the case for the world a whole.

Minor climatic fluctuations can destroy entire popula-

tions with marginal economies. In many societies wher technology is meagre and reaching adulthood an unce prospect, having many children is the only possible h against a desperate and uncertain future. Such a socie the grip of a consuming famine, for example, has litt lose. At a time when nuclear weapons are proliferatin conscionably, when an atomic device is almost a h handicraft industry, widespread famine and steep grad in affluence pose serious dangers to both the developed the underdeveloped worlds. The solution to such prob certainly requires better education, at least a degre technological self-sufficiency, and, especially, fair dist tion of the world's resources. But it also cries out for en adequate contraception – long-term, safe birth-control available for men as well as for women, perhaps to be t once a month or over even longer intervals. Such a dev ment would be very useful not just abroad but also at home, where considerable concern is being expre about the side effects of the conventional oestrogen contraceptives. Why is there no major effort for su development?

Many other technological initiatives are being prop and ought to be examined very seriously. They range the very cheap to the extremely expensive. At one end i technology – for example, the development of closed e gical systems involving algae, shrimp and fish which c be maintained in rural ponds and provide a highly nutri and extremely low-cost dietary supplement. At the oth the proposal of Gerard O'Neill of Princeton Universi construct large orbital cities that would, using lunar asteroidal materials, be self-propagating – one city h able to construct another from extraterrestrial resou Such cities in Earth orbit might be used in conve sunlight into microwave energy and beaming power dow Earth. The idea of independent cities in space – each per

ilt on differing social, economic or political assumptions, having different ethnic antecedents – is appealing, an portunity for those deeply disenchanted with terrestrial ilizations to strike out on their own somewhere else. In its rlier history, America provided such an opportunity for e restless, ambitious and adventurous. Space cities would a kind of America in the skies. They also would eatly enhance the survival potential of the human species. it the project is extremely expensive, costing at minimum out the same as one Vietnam war (in resources, not in es). In addition, the idea has the worrisome overtone of andoning the problems on the Earth – where, after all, f-contained pioneering communities can be established at uch less cost.

Clearly, there are more technological projects now pos-ole than we can afford. Some of them may be extremely st-effective but may have such large start-up costs as to main impractical. Others may require a daring initial in-stment of resources, which will work a benevolent revolu-on in our society. Such options have to be considered tremely carefully. The most prudent strategy calls for mbining low-risk/moderate-yield and moderate-risk/ gh-yield endeavours.

For such technological initiatives to be understood and pported, significant improvements in public understand-g of science and technology are essential. We are thinking ings. Our minds are our distinguishing characteristic as a ecies. We are not stronger or swifter than many other imals that share this planet with us. We are only smarter. addition to the immense practical benefit of having a ientifically literate public, the contemplation of science d technology permits us to exercise our intellectual facul-s to the limits of our capabilities. Science is an explora-on of the intricate, subtle and awesome universe we habit. Those who practice it know, at least on occasion, a

rare kind of exhilaration that Socrates said was the grea
of human pleasures. It is a communicable pleasure.
facilitate informed public participation in technolog
decision making, to decrease the alienation too m
citizens feel from our technological society, and for
sheer joy that comes from knowing a deep thing well
need better science education, a superior communicatio
its powers and delights. A simple place to start is to u
the self-destructive decline in federal scholarships
fellowships for science researchers and science teacher
the college, graduate and post-doctoral levels.

The most effective agents to communicate science to
public are television, motion pictures and newspape
where the science offerings are often dreary, inaccur
ponderous, grossly caricatured or (as with much Saturd
morning commercial television programming for child
hostile to science. There have been astonishing recent f
ings on the exploration of the planets, the role of s
brain proteins in affecting our emotional lives, the collis
of continents, the evolution of the human species (and
extent to which our past prefigures our future), the ultim
structure of matter (and the question of whether there
elementary particles or an infinite regress of them),
attempt to communicate with civilizations on planet
other stars, the nature of the genetic code (which determ
our heredity and makes us cousins to all the other plants
animals on our planet), and the ultimate questions of
origin, nature and fate of life, worlds and the universe
whole. Recent findings on these questions can be underst
by any intelligent person. Why are they so rarely discus
in the media, in schools, in everyday conversation?

Civilizations can be characterized by how they appro
such questions, how they nourish the mind as well as
body. The modern scientific pursuit of these questi
represents an attempt to acquire a generally accepted v

our place in the cosmos; it requires open-minded eativity, tough-minded scepticism and a fresh sense of onder. These questions are different from the practical ues I discussed earlier, but they are connected with such ues and – as in the example of Faraday and Maxwell – e encouragement of pure research may be the most reliable arantee available that we will have the intellectual and chnical wherewithal to deal with the practical problems cing us.

Only a small fraction of the most able youngsters enter ientific careers. I am often amazed at how much more pability and enthusiasm for science there is among elemen-y school youngsters than among college students. Some-ing happens in the school years to discourage their erest (and it is not mainly puberty); we must understand d circumvent this dangerous discouragement. No one can edict where the future leaders of science will come from. is clear that Albert Einstein became a scientist in spite , not because of, his schooling (Chapter 3). In his *Auto-ography*, Malcolm X describes a numbers runner who ver wrote down a bet but carried a lifetime of transactions rfectly in his head. What contributions to society, alcolm asked, would such a person have made with equate education and encouragement? The most brilliant ungsters are a national and a global resource. They quire special care and feeding.

Many of the problems facing us may be soluble, but only we are willing to embrace brilliant, daring and complex lutions. Such solutions require brilliant, daring and com-ex people. I believe that there are many more of them ound – in every nation, ethnic group and degree of luence – than we realize. The training of such youngsters ust not, of course, be restricted to science and technology; deed, the compassionate application of new technology to man problems requires a deep understanding of human

nature and human culture, a general education i broadest sense.

We are at a crossroads in human history. Never b has there been a moment so simultaneously perilou promising. We are the first species to have taken our e tion into our own hands. For the first time we posse means for intentional or inadvertent self-destructio also have, I believe, the means for passing through this of technological adolescence into a long-lived, rich an filling maturity for all the members of our species. But is not much time to determine to which fork of the ro are committing our children and our future.

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PART II

THE PARADOXERS

CHAPTER 5

NIGHT WALKERS AND MYSTERY MONGERS: SENSE AND NONSENSE AT THE EDGE OF SCIENCE

* * *

PLANT'S HEARTBEAT THRILLS SCIENTISTS AT OXFORD MEETING
Hindu savant causes further sensation by
showing 'blood' of plant flowing

AUDIENCE SITS ABSORBED
Watches with rapt attention as lecturer submits
snapdragon to death struggle

The New York Times
August 7, 1926, page 1

William James used to preach the 'will to believe'.
For my part, I should wish to preach the
'will to doubt' ... What is wanted is not the will to believe,
but the wish to find out, which is the exact opposite.

BERTRAND RUSSELL,
Sceptical Essays (1928)

GREECE of the second century A.D., during the reign of
e Roman Emperor Marcus Aurelius, there lived a master
n man named Alexander of Abonutichus. Handsome,
ver and totally unscrupulous, in the words of one of his
ntemporaries, he 'went about living on occult preten-
sions'. In his most famous imposture, 'he rushed into the
rketplace, naked except for a gold-spangled loincloth;
th nothing but this and his scimitar, and shaking his long,

loose hair, like fanatics who collect money in the nam
Cybele, he climbed on to a lofty altar and delivere
harangue' predicting the advent of a new and oracular
Alexander then raced to the construction site of a ten
the crowd streaming after him, and discovered – wher
had previously buried it – a goose egg in which he had se
up a baby snake. Opening the egg, he announced
snakelet as the prophesied god. Alexander retired to
house for a few days, and then admitted the breat
crowds, who observed his body now entwined with a
serpent: the snake had grown impressively in the inter

The serpent was, in fact, of a large and conveniently d
variety, procured for this purpose earlier in Macedonia.
outfitted with a linen head of somewhat human coun
ance. The room was dimly lit. Because of the press o
crowd, no visitor could stay for very long or inspect
serpent very carefully. The opinion of the multitude was
the seer had indeed delivered a god.

Alexander then pronounced the god ready to an
written questions delivered in sealed envelopes. When a
he would lift off or duplicate the seal, read the mes
remake the envelope and attach a response. People flo
from all over the Empire to witness this marvel, an orac
serpent with the head of a man. In those cases where
oracle later proved not just ambiguous but grossly wr
Alexander had a simple solution: he altered his record o
response he had given. And if the question of a rich
or woman revealed some weakness or guilty secret, A
ander did not scruple at extortion. The result of all
imposture was an income equivalent today to sev
hundred thousand dollars per year and fame rivalled by
men of his time.

We may smile at Alexander the Oracle-Monger. Of co
we all would like to foretell the future and make co
with the gods. But we would not nowadays be taken

:h a fraud. Or would we? M. Lamar Keene spent rteen years as a spiritualist medium. He was pastor of the w Age Assembly Church in Tampa, a trustee of the .iversal Spiritualist Association, and for many years a ding figure in the mainstream of the American spiritualist ivement. He is also a self-confessed fraud who believes, m first-hand knowledge, that virtually all spirit readings, nces and mediumistic messages from the dead are con- ous deceptions, contrived to exploit the grief and longing feel for deceased friends and relatives. Keene, like Alex- der, would answer questions given to him in sealed velopes – in this case not in private, but on the pulpit. He wed the contents with a concealed bright lamp or by caring lighter fluid, either of which can render the en- ope momentarily transparent. He would find lost objects, sent people with astounding revelations about their vate lives which 'no one could know', commune with spirits and materialize ectoplasm in the darkness of the nce – all based on the simplest tricks, an unswerving self- ıfidence, and most of all, on the monumental credulity, utter lack of scepticism he found in his parishioners and nts. Keene believes, as did Harry Houdini, that not only uch fraud rampant among the spiritualists, but also that y are highly organized to exchange data on potential nts, in order to make the revelations of the séance more onishing. Like the viewing of Alexander's serpent, the nces all take place in darkened rooms – because the ception would be too easily penetrated in the light. In his ık-earning years, Keene earned about as much, in uivalent purchasing power, as Alexander of Abonutichus. From Alexander's time to our own – indeed, probably for long as human beings have inhabited this planet – people ve discovered they could make money by pretending to ane or occult knowledge. A charming and enlightening count of some of these bamboozles can be found in a

remarkable book published in 1852 in London, *E*
ordinary Popular Delusions and the Madness of Crowd
Charles Mackay. Bernard Baruch claimed that the
saved him millions of dollars – presumably by alerting
to which idiot schemes he should not invest his mone
Mackay's treatment ranges from alchemy, prophecy
faith healing, to haunted houses, the Crusades, and
'influence of politics and religion on the hair and be
The value of the book, like the account of Alexande
Oracle-Monger, lies in the remoteness of the frauds
delusions described. Many of the impostures do not h
contemporary ring and only weakly engage our passio
becomes clear how people in other times were deceived
after reading many such cases, we begin to wonder wha
comparable contemporary versions are. People's feeling
as strong as they always were, and scepticism is probab
unfashionable today as in any other age. Accordingly,
ought to be bamboozles galore in contemporary soc
And there are.

In Alexander's time, as in Mackay's, religion wa
source of most accepted insights and prevailing world v
Those intent on duping the public often did so in relig
language. This is, of course, still being done, as the
mony of penitent spiritualists and other late-breaking
amply attests. But in the past hundred years – whethe
good or for ill – science has emerged in the popular
as the primary means of penetrating the secrets o
universe, so we should expect many contemporary
boozles to have a scientific ring. And they do.

Within the last century or so, many claims have
made at the edge or border of science – assertions that e
popular interest and, in many cases, that would be of
found scientific importance if only they were true. We
shortly examine a representative sampling of them. T
claims are out of the ordinary, a break from the humd

rld, and often imply something hopeful: for example, that have vast, untapped powers, or that unseen forces are out to save us from ourselves, or that there is a still acknowledged pattern and harmony to the universe. Well, ence does sometimes make such claims – as, for example, realization that the hereditary information we pass from eration to generation is encoded in a single long lecule called DNA, in the discovery of universal gravita- n or continental drift, in the tapping of nuclear energy, in earch on the origin of life or on the early history of the verse. So if some additional claim is made – for example, t it is possible to float in the air unaided, by a special ort of will – what is so different about that? Nothing. cept for the matter of proof. Those who claim that levita- n occurs have an obligation to demonstrate their con- tion before sceptics, under controlled conditions. The rden of proof is on them, not on those who might be bious. Such claims are too important to think about elessly. Many assertions about levitation have been made the last hundred years, but motion pictures of well- minated people rising unassisted fifteen feet into the air ve never been taken under conditions which exclude ud. If levitation were possible, its scientific and, more nerally, its human implications would be enormous. ose who make uncritical observations or fraudulent ims lead us into error and deflect us from the major nan goal of understanding how the world works. It is this reason that playing fast and loose with the truth very serious matter.

ASTRAL PROJECTION

NSIDER WHAT is sometimes called astral projection. Under nditions of religious ecstasy or hypnagogic sleep, or some- es under the influence of a hallucinogen, people report

the distinct sensation of stepping outside the body, lea
it, floating effortlessly to some other place in the room (
near the ceiling), and only at the end of the experi
remerging with the body. If such a thing can act
happen, it is certainly of great importance; it implies s
thing about the nature of human personality and even a
the possibility of 'life after death'. Indeed, some people
have had near-death experiences, or who have been decl
clinically dead and then revived, report similar sensat
But the fact that a sensation is reported does not
that it occurred as claimed. There might, for example,
common experience or wiring defect in human ne
anatomy that under certain circumstances always lea
the same illusion of astral projection. (See Chapter 25

There is a simple way to test astral projection. In
absence, have a friend place a book face up on a high
inaccessible shelf in the library. Then, if you ever hav
astral projection experience, float to the book and rea
title. When your body reawakens and you correctly
nounce what you have read, you will have provided
evidence for the physical reality of astral projection.
of course, there must be no other way for you to know
title of the book, such as sneaking a peek when no one e
around, or being told by your friend or by someone
friend tells. To avoid the latter possibility, the experi
should be done 'double blind'; that is, someone quite
known to you who is entirely unaware of your existence
select and place the book and judge whether your an
is correct. To the best of my knowledge no demonstrati
astral projection has ever been reported under such
trolled circumstances with sceptics in attendance. I conc
that while astral projection is not excluded, there is
reason to believe in it. On the other hand, there is s
evidence accumulated by Ian Stevenson, a Universit
Virginia psychiatrist, that young children in India and

:r East report in great detail a previous life in a moder-
y distant locale which they have never visited, while
her inquiry demonstrates that a recently deceased person
the child's description very well. But this is not an
:riment performed under controlled conditions, and it is
:ast possible that the child has overheard or been given
rmation about which the investigator is unaware.
·enson's work is probably the most interesting of all
temporary research on 'extrasensory perception'.

SPIRIT RAPPING

'UPSTATE NEW YORK in 1848 there lived two little girls,
rgaret and Kate Fox, about whom marvellous stories
: told. In their presence could be heard mysterious
ping noises, later understood to be coded messages from
spirit world: Ask the spirits anything – one rap signifies
three raps signify yes. The Fox sisters became a sensa-
, embarked on nationwide tours organized by their elder
:r, and became the focus of rapt attention from European
llectuals and literati such as Elizabeth Barrett Browning.
'manifestations' brought about by the Fox sisters are the
·ins of modern spiritualism, the belief that by some
:ial effort of will a few gifted people are able to
mmunicate with the spirits of the dead. Keene's associates
: a substantial debt to the Fox sisters.

orty years after the first 'manifestations', provoked by
uneasy conscience, Margaret Fox produced a signed
fession. The raps were made – in a standing position with
apparent effort or movement – by cracking the toe and
le joints, very much like cracking knuckles. 'And that is
way we began. First, as a mere trick to frighten mother,
then, when so many people came to see us children, we
: ourselves frightened, and for self-preservation forced to
p it up. No one suspected us of any trick because we

were such young children. We were led on by my
purposely and by mother unintentionally.' The eldest s
who organized their tours, seems to have been fully
scious of the fraud. Her motive was money.

The most instructive aspect of the Fox case is not th
many people were bamboozled; but rather that afte
hoax was confessed, after Margaret Fox made a p
demonstration, on the stage of a New York theatre, o
'preternatural big toe', many who had been taken in
refused to acknowledge the fraud. They pretended
Margaret had been coerced into the confession by
rationalist Inquisition. People are rarely grateful
demonstration of their credulity.

THE CARDIFF GIANT

IN 1869 THE FIGURE of a larger-than-life stone man
unearthed by a farmer 'while digging a well' near the v
of Cardiff in western New York. Clergymen and scie
alike asserted that it was a fossilized human being from
past, perhaps a confirmation of the Biblical account: 'T
were giants in those days.' Many commented on the s
of the figure, seemingly far finer than a mere artisan c
have carved from stone. Why, there were even netwo
tiny blue veins. But others were less impressed, incl
Andrew Dickson White, the first president of Co
University, who declared it to be a pious fraud,
execrable sculpture to boot. A meticulous examination
revealed it to be of very recent origin, whereup
emerged that the Cardiff Giant was merely a statue, a
engineered by George Hull of Binghamton, who desc
himself as 'tobacconist, inventor, alchemist, atheist', a
man. The 'blue veins' were a natural pattern in the scu
rock. The object of the deception was to fleece touris

But this uncomfortable revelation did not faze

erican entrepreneur P. T. Barnum, who offered $60,000
a three-month lease on the Cardiff Giant. When Barnum
ed to secure it for travelling exhibition (the owners were
king too much money to give it up), he simply had a
y made and exhibited *it*, to the awe of his customers
l the enrichment of his pocketbook. The Cardiff Giant
t most Americans have seen is this copy. Barnum
ibited a fake fake. The original is today languishing at
Farmer's Museum in Cooperstown, New York. Both
num and H. L. Mencken are said to have made the
ressing observation that no one ever lost money by
lerestimating the intelligence of the American public. The
ıark has worldwide application. But the lack is not in
lligence, which is in plentiful supply; rather, the scarce
ımodity is systematic training in critical thinking.

CLEVER HANS, THE MATHEMATICAL HORSE

THE EARLY YEARS of the twentieth century there was a
se in Germany who could read, do mathematics and
ibit a deep knowledge of world political affairs. Or so it
ned. The horse was called Clever Hans. He was owned by
helm von Osten, an elderly Berliner whose character
s such, everyone said, that fraud was out of the question.
egations of distinguished scientists viewed the equine
rvel and pronounced it genuine. Hans would reply to
thematical problems put to him with coded taps of his
leg, and would answer nonmathematical questions by
lding his head up and down or shaking it side to side in
conventional Western way. For example, someone
uld say, 'Hans, how much is twice the square root of
e, less one?' After a moment's pause Hans would dutifully
se his right foreleg and tap five times. Was Moscow
capital of Russia? Head shake. How about St. Peters-
g? Nod.

The Prussian Academy of Sciences sent a comm
headed by Oskar Pfungst, to take a closer look; Oste
believed fervently in Hans's powers, welcomed the i
Pfungst noticed a number of interesting regularities.
times, the more difficult the question, the longer i
Hans to answer; or when Osten did not know the a
Hans exhibited a comparable ignorance; or when Ost
out of the room, or when the horse was blindfold
correct answers were forthcoming. But other times
would get the right answer in a strange place, surro
by sceptics, with Osten not only out of the room, but
town. The solution eventually became clear. W
mathematical question was put to Hans, Osten
become slightly tense, for fear Hans would make t
taps. When Hans, however, reached the correct num
taps, Osten unconsciously and imperceptibly nod
relaxed – imperceptibly to virtually all human observe
not to Hans, who was rewarded with a sugar cu
correct answers. Even teams of sceptics would watch
foot as soon as the question was put and make gest
postural responses when the horse reached the right a
Hans was totally ignorant of mathematics, but very se
to unconscious nonverbal cues. Similar signs were un
ingly transmitted to the horse when verbal question
posed. Clever Hans was aptly named; he was a hors
had conditioned one human being and discovered tha
human beings he had never before met would provi
the needed cues. But despite the unambiguous nat
Pfungst's evidence, similar stories of counting, readi
politically sage horses, pigs and geese have contin
plague the gullible of many nations.*

* For example, Lady Wonder, a horse from Virginia, could answ
tions by arranging lettered wood blocks with her nose. Since
replied to queries posed privately to her owner, she was pronou
only literate but telepathic by the parapsychologist J. B. Rhine (*J*

PRECOGNITIVE DREAMS

: OF THE MOST striking apparent instances of extrasensory
:eption is the precognitive experience, when a person has
)mpelling perception of an imminent disaster, the death
. loved one, or a communication from a long-lost friend,
the predicted event then transpires. Many who have
such experiences report that the emotional intensity of
precognition and its subsequent verification provide an
rpowering sense of contact with another realm of reality.
ıve had such an experience myself. Many years ago I
)ke in the dead of night in a cold sweat, with the certain
wledge that a close relative had suddenly died. I was so
)ped with the haunting intensity of the experience that I
afraid to place a long-distance phone call, for fear that
relative would trip over the telephone cord (or some-
ıg) and make the experience a self-fulfilling prophecy.
'act, the relative is alive and well, and whatever psycho-
cal roots the experience may have, it was not a reflection
ın imminent event in the real world.
However, suppose the relative had in fact died that night.
ı would have had a difficult time convincing me that it
merely coincidence. But it is easy to calculate that if
ı American has such a premonitory experience a few
:s in his lifetime, the actuarial statistics alone will pro-
:e a few *apparent* precognitive events somewhere in
erica each year. We can calculate that this must occur
ly frequently, but to the rare person who dreams of

)rmal and Social Psychology, 23*, 449, 1929). The magician John Scarne
d the owner would intentionally signal the horse with a whip as Lady
der moved her head over the blocks, preparatory to nudging them
words. The owner seemed to be out of the horse's field of view, but
es have excellent peripheral vision. Unlike Clever Hans, Lady Wonder
an accomplice in an intentional fraud.

disaster, followed rapidly by its realization, it is un
and awesome. Such a coincidence must happen to *so*
every few months. But those who experience a c
precognition understandably resist its explanati
coincidence.

After my experience I did not write a letter to an in
of parapsychology relating a compelling predictive
which was not borne out by reality. That is not a mem
letter. But had the death I dreamt actually occurred,
letter would have been marked down as evidence fo
cognition. The hits are recorded, the misses are not.
human nature unconsciously conspires to produce a
reporting of the frequency of such events.

THESE CASES – Alexander the Oracle-Monger, Keene,
projection, the Fox sisters, the Cardiff Giant, Clever
and precognitive dreams – are typical of claims ma
the boundary or edge of science. An amazing assert
made, something out of the ordinary, marvellous or
some – or at least not tedious. It survives supe
scrutiny by lay people and, sometimes, more detailed
and more impressive endorsement by celebrities and
tists. Those who accept the validity of the assertion
all attempts at conventional explanation. The most co
correct explanations are of two sorts. One is con
fraud, usually by those with a financial interest
outcome, as with the Fox sisters and the Cardiff
Those who accept the phenomena have been bambo
The other explanation often applies when the phen
are uncommonly subtle and complex, when nature is
intricate than we have guessed, when deeper stu
required for understanding; Clever Hans and many
cognitive dreams fit this second explanation. Here
often, we bamboozle ourselves.

I have chosen the foregoing cases for another re

y are all closely involved with everyday life – human or nal behaviour, evaluating the reliability of evidence, sions for the exercise of common sense. None of these s involve technological complexities or arcane theoreti- levelopments. We do not need an advanced degree in ics, let us say, to have our sceptical hackles rise at the entions of modern spiritualists. Nevertheless, these tes, impostures and misapprehensions have captivated ons. How much more dangerous and difficult to assess t be borderline claims at the edge of less familiar sciences out cloning, say, or cosmic catastrophes or lost con- nts or unidentified flying objects?

make a distinction between those who perpetrate and note borderline belief systems and those who accept n. The latter are often taken by the novelty of the ems, and the feeling of insight and grandeur they ide. These are in fact scientific attitudes and scientific s. It is easy to imagine extraterrestrial visitors who ed like human beings, and flew space vehicles and even anes like our own, and taught our ancestors civilization. does not strain our imaginative powers overly and is ciently similar to familiar Western religious stories to comfortable. The search for Martian microbes of ic biochemistry, or for interstellar radio messages from ligent beings biologically very dissimilar is more difficult rasp and not as comforting. The former view is widely eyed and available; the latter much less so. Yet I think y of those excited by the idea of ancient astronauts are ivated by sincere scientific (and occasionally religious) ngs. There is a vast untapped popular interest in the est scientific questions. For many people, the shoddily ght out doctrines of borderline science are the closest oximation to comprehensible science readily available. popularity of borderline science is a rebuke to the ols, the press and commercial television for their sparse,

uninaginative and ineffective efforts at science educ
and to us scientists, for doing so little to populariz
subject.

Advocates of ancient astronauts – the most notable
Erich von Däniken in his book *Chariots of the Gods?* –
that there are numerous pieces of archaeological evi
that can be understood only by past contact by
terrestrial civilizations with our ancestors. An iron pi
India; a plaque in Palenque, Mexico; the pyramids of E
the stone monoliths (all of which, according to
Bronowski, resemble Benito Mussolini) on Easter I
and the geometrical figures in Nazca, Peru, are all a
to have been manufactured by or under the supervis
extraterrestrials. But in every case the artifacts in qu
have plausible and much simpler explanations. Our
tors were no dummies. They may have lacked high
nology, but they were as smart as we, and they some
combined dedication, intelligence and hard work to pr
results that impress even us. The ancient-astronaut
interestingly, is popular among bureaucrats and polit
in the Soviet Union, perhaps because it preserves th
religious ideas in an acceptably modern scientific co
The most recent version of the ancient-astronaut story
claim that the Dogon people in the Republic of Mal
an astronomical tradition concerning the star Sirius
they could only have acquired by contact with an
civilization. This seems, in fact, to be the correct ex
tion, but it has nothing to do with astronauts, anci
modern. (See Chapter 6.)

It is surprising that pyramids have played a r
ancient-astronaut writings; ever since the Napoleon
vasions of Egypt impressed ancient Egyptian civilizat
the consciousness of Europe, they have been the focu
great deal of nonsense. Much has been written abou
posed numerological information stored in the dime

he pyramids, especially the great pyramid of Gizeh, so
, for example, the ratio of height to width in certain
s is said to be the time between Adam and Jesus in
rs. In one famous case a pyramidologist was observed
g a protuberance so that the observations and his
culations would be in better accord. The most recent
nifestation of interest in pyramids is 'pyramidology', the
tention that we and our razor blades feel better and last
ger inside pyramids than we and they do inside cubes.
ybe. I find living in cubical dwellings depressing, and
most of our history human beings did not live in
h quarters. But the contentions of pyramidology,
ier appropriately controlled conditions, have never
n verified. Again, the burden of proof has not been
.

he Bermuda Triangle 'mystery' has to do with un-
lained disappearances of ships and airplanes in a vast
on of the ocean around Bermuda. The most reasonable
lanation for these disappearances (when they actually
ur; many of the alleged disappearances turn out simply
er to have happened) is that the vessels sank. I once
ected on a television programme that it seemed strange
ships and airplanes to disappear mysteriously but never
ns; to which the host, Dick Cavett, replied, 'I can see
've never waited for the Long Island Railroad.' As with
ancient-astronaut enthusiasts, the Bermuda Triangle
ocates use sloppy scholarship and rhetorical questions.
they have not provided compelling evidence. They have
met the burden of proof.

lying saucers, or UFOs, are well known to almost every-
. But seeing a strange light in the sky does not mean
t we are being visited by beings from the planet Venus
a distant galaxy named Spectra. It might, for example,
an automobile headlight reflected off a high-altitude
ud, or a flight of luminescent insects, or an unconven-

tional aircraft, or a conventional aircraft with uncc
tional lighting patterns, such as a high-intensity searc
used for meteorological observations. There are a
number of cases – closer encounters with some highish
numeral – where one or two people claim to have
taken aboard an alien spaceship, prodded and probec
unconventional medical instruments, and released. I
these cases we have only the unsubstantiated testimor
matter how heartfelt and seemingly sincere, of one c
people. To the best of my knowledge there are no ins
out of the hundreds of thousands of UFO reports filec
1947 – not a single one – in which many people inc
dently and reliably report a close encounter with w
clearly an alien spacecraft.

Not only is there an absence of good anecdotal evi
there is no physical evidence either. Our laboratories ar
sophisticated. A product of alien manufacture might r
be identified as such. Yet no one has ever turned up e
small fragment of an alien spacecraft that has passed an
physical test – much less the logbook of the starship ca
It is for these reasons that in 1977 NASA declin
invitation from the Executive Office of the Presid
undertake a serious investigation of UFO reports.
hoaxes and mere anecdotes are excluded, there seems
nothing left to study.

Once I spied a bright, 'hovering' UFO, and poin
out to some friends in a restaurant, soon found myself
midst of a throng of patrons, waitresses, cooks and pr
tors milling about on the sidewalk, pointing up into t
with fingers and forks, and making gasps of astonish
People were somewhere between delighted and awes
But when I returned with a pair of binoculars which c
showed the UFO to be an unconventional aircraft (a N
weather airplane, as it later turned out), there was un
disappointment. Some felt embarrassed at the pub

ıre of their credulity. Others were simply disappointed at evaporation of a good story, something out of the nary – a visitor from another world.

many such cases we are not unbiased observers. We an emotional stake in the outcome – perhaps merely use the borderline belief system, if true, makes the world re interesting place; but perhaps because there is some- g there that strikes more deeply into the human psyche. tral projection actually occurs, then it is possible for e thinking and perceiving part of me to leave my body effortlessly travel to other places – an exhilarating pect. If spiritualism is real, then my soul will survive leath of my body – possibly a comforting thought. If e is extrasensory perception, then many of us possess t talents that need only be tapped to make us more erful than we are. If astrology is right, then our per- lities and destinies are intimately tied to the rest of osmos. If elves and goblins and fairies truly exist (there lovely Victorian picture book showing photographs of ach-high undraped ladies with gossamer wings convers- with Victorian gentlemen), then the world is a more guing place than most adults have been led to believe. If re now being or in historical times have been visited presentatives from advanced and benign extraterrestrial izations, perhaps the human predicament is not so dire seems; perhaps the extraterrestrials will save us from elves. But the fact that these propositions charm or stir oes not guarantee their truth. Their truth depends only whether the evidence is compelling; and my own, and etimes reluctant, judgment is that compelling evidence hese and many similar propositions simply does not (at as yet) exist.

hat is more, many of these doctrines, if false, are icious. In simplistic popular astrology we judge people ne of twelve character types depending on their month

of birth. But if the typing is false, we do an injustice
people we are typing. We place them in previous
lected pigeonholes and do not judge them for themse
typing familiar in sexism and racism.

The interest in UFOs and ancient astronauts see
least partly the result of unfulfilled religious need
extraterrestrials are often described as wise, pov
benign, human in appearance, and sometimes th
attired in long white robes. They are very much lik
and angels, coming from other planets rather than
heaven, using spaceships rather than wings. There is
pseudoscientific overlay, but the theological antecede
clear: in many cases the supposed ancient astronau
UFO occupants are deities, feebly disguised and m
ized, but easily recognizable. Indeed, a recent British
suggests that more people believe in extraterrestrial
tions than in God.

Classical Greece was replete with stories in whi
gods came down to Earth and conversed with human
The Middle Ages were equally rich in apparitions of
and Virgins. Gods, saints and Virgins were all re
repeatedly over centuries by people of the highest ap
reliability. What has happened? Where have all the
gone? What has happened to the Olympian gods?
these beings simply abandoned us in recent and more
cal times? Or could these early reports reflect the su
tion and credulity and unreliability of witnesses? A
suggests a possible social danger from the prolifera
UFO cultism: if we believe that benign extraterrestri
solve our problems, we may be tempted to exert les
our full measure of effort to solve them ourselves –
occurred in millennialist religious movements many t
human history.

All the really interesting UFO cases depend on be
that one or a few witnesses were not bamboozling o

:led. Yet the opportunity for deception in eyewitness unts is breathtaking: (1) When a mock robbery is staged law school class, few of the students can agree on the ber of intruders, their clothing, weapons or comments, sequence of events or the time the robbery took. (2) :hers are presented with two groups of children who , unknown to them, tested equally well on all examina- s. But the teachers are informed that one group is smart the other dumb. The subsequent grades reflect that al and erroneous assessment, independent of the per- iance of the students. Predispositions bias conclusions. Witnesses are shown a motion picture of an automobile lent. They are then asked a series of questions such as the blue car run the stop sign?' A week later, when tioned again, a large proportion of the witnesses claim ave seen a blue car – despite the fact that no remotely car is in the film. There seems to be a stage, shortly an eyewitness event, in which we verbalize what we k we have seen and then forever after lock it into our iories. We are very vulnerable in that stage, and any ailing beliefs – in Olympian gods or Christian saints or terrestrial astronauts, say – can unconsciously in- ice our eyewitness account.

hose sceptical of many borderline belief systems are not ssarily those afraid of novelty. For example, many of my agues and I are deeply interested in the possibility of intelligent or otherwise, on other planets. But we must reful not to foist our wishes and fears upon the cosmos. ad, in the usual scientific tradition, our objective is to out what the answers really are, independent of our tional predispositions. If we are alone, that is a truth h knowing also. No one would be more delighted than intelligent extraterrestrials were visiting our planet. It ld make my job enormously easier. Indeed, I have spent e time than I care to think about on the UFO and ancient

astronaut questions. And public interests in these mat
I believe, at least in part, a good thing. But our openn
the dazzling possibilities presented by modern scienc
be tempered by some hard-nosed scepticism. Many in
ing possibilities simply turn out to be wrong. An ope
to new possibilities and a willingness to ask hard que
are both required to advance our knowledge. And the a
of tough questions has an ancillary benefit: politica
religious life in America, especially in the last decade
half, has been marked by an excessive public credul
unwillingness to ask difficult questions, which has pro
a demonstrable impairment in our national health.
sumer scepticism makes quality products. This may b
governments and churches and school systems d
exhibit unseemly zeal in encouraging critical thought.
know they themselves are vulnerable.

Professional scientists generally have to make a cho
their research goals. There are some objectives that wo
very important if achieved, but that promise so small a
hood of success that no one is willing to pursue them
many years this was the case in the search for extraterr
intelligence. The situation has changed mainly be
advances in radio technology now permit us to con
enormous radio telescopes with sensitive receivers t
up any messages that might be sent our way. Never b
in human history was this possible.) There are
scientific objectives that are perfectly tractable but
tirely trivial significance. Most scientists choose a n
course. As a result, very few scientists actually plung
the murky waters of testing or challenging borderli
pseudo-scientific beliefs. The chance of finding out
thing really interesting – except about human nature –
small, and the amount of time required seems large. I b
that scientists should spend more time in discussing
issues, but the fact that a given contention lacks vig

.tific opposition in no way implies that scientists think it
ısonable.

ıere are many cases where the belief system is so absurd
scientists dismiss it instantly but never commit their
ments to print. I believe this is a mistake. Science,
:ially today, depends upon public support. Because
people have, unfortunately, a very inadequate
vledge of science and technology, intelligent decision
ng on scientific issues is difficult. Some pseudoscience is
ɔfitable enterprise, and there are proponents who not
are strongly identified with the issue in question but
make large amounts of money from it. They are willing
ɔmmit major resources to defending their contentions.
: scientists seem unwilling to engage in public con-
.ations on borderline science issues because of the effort
ired and the possibility that they will be perceived to
a public debate. But it is an excellent opportunity
ıow how science works at its murkier borders, and
a way to convey something of its power as well as its
sures.

ıere is stodgy immobility on both sides of the borders
·e scientific enterprise. Scientific aloofness and opposi-
to novelty are as much a problem as public gullibility. A
ŋguished scientist once threatened to set then Vice
ident Spiro T. Agnew on me if I persisted in organizing
eting of the American Association for the Advancement
:ience in which both proponents and opponents of the
ıterrestrial-spacecraft hypothesis of UFO origins would
:rmitted to speak. Scientists offended by the conclusions
ınmanuel Velikovsky's *World in Collision* and irritated
/elikovsky's total ignorance of many well-established
:tific facts successfully and shamefully pressured Veli-
ky's publisher to abandon the book – which was then
ɔut by another firm, much to its profit – and when I
ŋged for a second AAAS symposium to discuss Veli-

kovsky's ideas, I was criticized by a different leading s
who argued that any public attention, no matter hov
tive, could only aid Velikovsky's cause.

But these symposia were held, the audiences see
find them interesting, the proceedings were publishe
now youngsters in Duluth or Fresno can find some
presenting the other side of the issue in their librari
page 76.) If science is presented poorly in schools a
media, perhaps some interest can be aroused by
prepared, comprehensible public discussions at the e
science. Astrology can be used for discussions of astro
alchemy for chemistry; Velikovskian catastrophism a
continents such as Atlantis for geology; and spirit
and Scientology for a wide range of issues in psyc
and psychiatry.

There are still many people in the United State
believe that if a thing appears in print it must be true. S
much undemonstrated speculation and rampant no
appears in books, a curiously distorted view of what
emerges. I was amused to read – in the furore that fo
the premature newspaper release of the contents of
by H. R. Haldeman, a former presidential assistant a
victed felon – what the editor in chief of one of the
publishing companies in the world had to say: 'We be
publisher has an obligation to check out the accu
certain controversial non-fiction works. Our procedu
send the book out for an objective reading by an ind
ent authority in the field.' This is by an editor who
has in fact published some of the most egregious p
science of recent decades. But books presenting the
side of the story are now becoming available, and
accompanying box I have listed a few of the more pro
pseudoscientific doctrines and recent attempts at thei
tific refutation. One of the contentions criticized
plants have emotional lives and musical preferences –

flurry of interest a few years ago, including weeks of ersations with vegetables in Gary Trudeau's 'Doones-' comic strip. As an epigraph to this chapter (on the ı struggle of the snapdragon) shows, it is an old con-on. Perhaps the only encouraging point is that it is being ed more sceptically today than it was in 1926.

N YEARS AGO a committee of scientists, magicians and rs was organized to provide some focus for scepticism he border of science. This nonprofit organization is d 'The Committee for the Scientific Investigation of ns of the Paranormal' and is at 923 Kensington Avenue, alo, N. Y. 14215. It is beginning to do some useful work, ding in its publications the latest news on the confron-n between the rational and the irrational – a debate that back to the encounters between Alexander the Oracle-ger and the Epicureans, who were the rationalists of his The committee has also made official protests to the orks and the Federal Communications Commission it television programmes on pseudoscience that are par-arly uncritical. An interesting debate has gone on within committee between those who think that all doctrines smell of pseudoscience should be combated and those believe that each issue should be judged on its own ts, but that the burden of proof should fall squarely on e who make the proposals. I find myself very much in atter camp. I believe that the extraordinary should cer-ly be pursued. But extraordinary claims require extra-nary evidence.

ientists are, of course, human. When their passions are ed they may abandon temporarily the ideals of their pline. But these ideals, the scientific method, have ed enormously effective. Finding out the way the world y works requires a mix of hunches, intuition and ant creativity; it also requires sceptical scrutiny of every

SOME RECENT BORDERLINE DOCTRINES AND THEIR C

While many recent borderline doctrines are wi
moted, sceptical discussion and dissection of their f
are not so widely known. This table is a guide to
these critiques.

Bermuda Triangle	*The Bermuda Triangle Mystery* Laurence Kusche, Harper & Row
Spiritualism	*A Magician Among the Spirits*, Harry Houdini, Harper, 1924
	The Psychic Mafia, M. Lamar Keene, St. Martin's Pre
Uri Geller	*The Magic of Uri Geller*, James Randi, Ballantine, 1975
Atlantis and other 'lost continents'	*Legends of the Earth: Their Geolog* *Origins*, Dorothy B. Vitaliano, Indiana U Press, 1973
	Lost Continents, L. Sprague de Camp, Ballantine,
UFO*s*	*UFOs Explained*, Philip Klass, Random House, 197
	UFOs: A Scientific Debate, Carl Sagan and Thornton Page, ec ton, 1973
Ancient Astronauts	*The Space Gods Revealed: A Close* *the Theories of Erich von Däniken*, Ronald Story, Harper & Row, 197
	The Ancient Engineers, L. Sprague de Camp, Ballantine, 1
Velikovsky: *Worlds in Collision*	*Scientists Confront Velikovsky*, Donald Goldsmith, ed., Cornell University Press, 1977
The Emotional Lives of Plants	'Plant "Primary Perception"', K. A. Horowitz and others, *Scienc* 189: 478–480 (1975)

It is the tension between creativity and scepticism that produced the stunning and unexpected findings of ce. In my opinion the claims of borderline science pall mparison with hundreds of recent activities and dis-ries in real science, including the existence of two semi-pendent brains within each human skull; the reality of holes, continental drift and collisions; chimpanzee uage; massive climatic changes on Mars and Venus; the quity of the human species; the search for extraterrestrial the elegant self-copying molecular architecture that rols our heredity and evolution; and observational evi-e on the origin, nature and fate of the universe as a le.

it the success of science, both its intellectual excitement its practical application, depend upon the self-correcting acter of science. There must be a way of testing any l idea. It must be possible to reproduce any valid experi-t. The character or beliefs of the scientist are irrelevant; hat matters is whether the evidence supports his con-on. Arguments from authority simply do not count, too y authorities have been mistaken too often. I would like e these very effective scientific modes of thought com-icated by the schools and the media; and it would inly be an astonishment and delight to see them intro-d into politics. Scientists have been known to change minds completely and publicly when presented with arguments. I cannot recall the last time a politician dis-ed a similar openness and willingness to change.

any of the belief systems at the edge or fringe of science ot subject to crisp experimentation. They are anecdotal, nding entirely on the validity of eyewitnesses who, neral, are notoriously unreliable. On the basis of past ormance most such fringe systems will turn out to be lid. But we cannot reject out of hand, any more than we accept at face value, all such contentions. For example,

the idea that large rocks can drop from the skies
sidered absurd by eighteenth-century scientists;
Jefferson remarked about one such account that
rather believe that two Yankee scientists lied t
stones fell from the heavens. Nevertheless, stone
from the heavens. They are called meteorites, and
conceptions have no bearing on the truth of the ma
the truth was established only by a careful analysis c
of independent witnesses to a common meteorite f
ported by a great body of physical evidence, in
meteorites recovered from the eaves of houses
furrows of ploughed fields.

Prejudice means literally pre-judgment, the reject
contention out of hand, before examining the ev
Prejudice is the result of powerful emotions, not o
reasoning. If we wish to find out the truth of a ma
must approach the question with as nearly open a
we can, and with a deep awareness of our own lim
and predispositions. On the other hand, if after c
and openly examining the evidence, we reject the p
tion, that is not prejudice. It might be called 'post-ju
is certainly a prerequisite for knowledge.

Critical and sceptical examination is the method
everyday practical matters as well as in science. When
a new or used car, we think it prudent to insist on
warranties, test drives and checks of particular pa
are very careful about car dealers who are evasive c
points. Yet the practitioners of many borderline bel
offended when subjected to similarly close scrutiny
who claim to have extrasensory perception also cla
their abilities decline when they are carefully watch
magician Uri Geller is happy to warp keys and cu
the vicinity of scientists – who, in their confron
with nature, are used to an adversary who fights fai
greatly affronted at the idea of performances bef

ence of sceptical magicians – who, understanding an limitations, are themselves able to perform similar ts by sleight of hand. Where sceptical observation and ission are suppressed, the truth is hidden. The pro- nts of such borderline beliefs, when criticized, often t to geniuses of the past who were ridiculed. But the hat some geniuses were laughed at does not imply that vho are laughed at are geniuses. They laughed at mbus, they laughed at Fulton, they laughed at the ght brothers. But they also laughed at Bozo the Clown. ie best antidote for pseudoscience, I firmly believe, is nce:

There is an African fresh-water fish that is blind. It rates a standing electric field, through perturbations in h it distinguishes between predators and prey and com- icates in a fairly elaborate electrical language with ntial mates and other fish of the same species. This lves an entire organ system and sensory capability pletely unknown to pretechnological human beings.

There is a kind of arithmetic, perfectly reasonable and contained, in which two times one does not equal one s two.

Pigeons – one of the least prepossessing animals on h – are now found to have a remarkable sensitivity to netic-field strengths as small as one hundred thousandth of the Earth's magnetic dipole. Pigeons evidently use capability for navigation and sense their surroundings eir magnetic signatures: metal gutters, electrical power , fire escapes and the like – a sensory modality glimpsed o human being who ever lived.

Quasars seem to be explosions of almost unimaginable nce in the hearts of galaxies which destroy millions of ds, many of them perhaps inhabited.

In an East African volcanic ash flow 3.5 million years here are footprints – of a being about four feet high with

a purposeful stride that may be the common ancestor
and men. Nearby are the prints of a knuckle-w
primate corresponding to no animal yet discovered.

▪ Each of our cells contains dozens of tiny factories
mitochondria which combine our food with mo
oxygen in order to extract energy in convenient form.
evidence suggests that billions of years ago the mitoch
were free organisms which have slowly evolved
mutually dependent relation with the cell. When
celled organisms arose, the arrangement was retaine
very real sense, then, we are not a single organism,
array of about ten trillion beings and not all of the
kind.

▪ Mars has a volcano almost 80,000 feet high whic
constructed about a billion years ago. An even
volcano may exist on Venus.

▪ Radio telescopes have detected the cosmic black
background radiation, the distant echo of the event
the Big Bang. The fires of creation are being observed

I could continue such a list almost indefinitely. I believ
even a smattering of such findings in modern scienc
mathematics is far more compelling and exciting than
of the doctrines of pseudoscience, whose practitioner
condemned as early as the fifth century B.C. by the
philosopher Heraclitus as 'night-walkers, magicians,
of Bacchus, priestesses of the wine-vat, mystery-mo
But science is more intricate and subtle, reveals a
richer universe, and powerfully evokes our sense of w
And it has the additional and important virtue – to wh
extent the word has any meaning – of being true.

CHAPTER 6

WHITE DWARFS AND LITTLE GREEN MEN

* * *

No testimony is sufficient to establish a miracle,
less ... its falsehood would be more miraculous than the fact
which it endeavours to establish.

DAVID HUME
Of Miracles

NITY HAS already achieved interstellar spaceflight. a gravitational assist from the planet Jupiter, the er 10 and 11 and the Voyager 1 and 2 spacecraft have boosted into trajectories that will leave the solar system e realm of the stars. They are very slow-moving space- despite the fact that they are the fastest objects ever hed by our species. They will take tens of thousands of to travel typical interstellar distances. Unless some al effort is made to redirect them, they will never enter ier planetary system in all the tens of billions of years ure history of the Milky Way Galaxy. The star-to-star nces are too large. They are doomed to wander forever e dark between the stars. But even so, these spacecraft messages attached to them for the remote contingency at some future time, alien beings might intercept the craft and wonder about the beings who launched them iese prodigious journeys.*

detailed discussion of the Pioneer 10 and 11 plaque can be found in ok *The Cosmic Connection* (New York, Doubleday, 1973); and the graph records aboard Voyager 1 and 2 are comprehensively ped in *Murmurs of Earth: The Voyager Interstellar Record* (New Random House, 1978).

If we are capable of such constructions at our c
tively backward technological stage, might not a civ
thousands or millions of years more advanced tha
on a planet of another star, be capable of fa
directed interstellar travel? Interstellar spaceflight
consuming, difficult and expensive for us, and perha
for other civilizations with substantially greater re
than ours. But it surely would be unwise to conte
conceptually novel approaches to the physics or engi
of interstellar spaceflight will not be discovered by u
time in the future. It is evident that for economy, ef
and convenience, interstellar radio transmission i
superior to interstellar spaceflight, and this is the reas
our own efforts have concentrated strongly on radi
munication. But radio communication is clearly in
priate for contact with a pretechnological society or
No matter how clever or powerful the transmiss
such radio message would have been received or und
on Earth before the present century. And there has b
on our planet for about four billion years, human be
several million, and civilization for perhaps ten tho

It is not inconceivable that there is a kind of G
Survey, established by cooperating civilizations or
planets throughout the Milky Way Galaxy, which k
eye (or some equivalent organ) on emerging plan
seeks out undiscovered worlds. But the solar system
far from the centre of the Galaxy and could well have
such searches. Or survey ships may come here, but on
ten million years, say – with none having arrived
historical times. However, it is also possible that a few
teams have arrived recently enough in human hist
their presence to have been noted by our ancestors,
for human history to have been affected by the con

The Soviet astrophysicist I. S. Shklovskii and I di
this possibility in our book, *Intelligent Life in the U*

966. We examined a range of artifacts, legends and ore from many cultures and concluded that not one of cases provided even moderately convincing evidence xtraterrestrial contact. There are always more plausible native explanations based on known human abilities behaviour. Among the cases discussed were a number accepted by Erich von Däniken and other uncritical rs as valid evidence for extraterrestrial contact: erian legends and astronomical cylinder seals; the cal stories of the Slavonic Enoch and of Sodom and orrah; the Tassili frescoes in North Africa; the ma-d metal cube allegedly found in ancient geological sedi-s and said to be displayed in a museum in Austria; and n. Over the years I have continued to look as deeply as I able into such stories and have found very few that ire more than passing attention.

the long litany of 'ancient astronaut' pop archaeology, cases of apparent interest have perfectly reasonable native explanations, or have been misreported, or are le prevarications, hoaxes and distortions. This descrip- applies to arguments about the Piri Reis map, the er Island monoliths, the heroic drawings on the plains azca, and various artifacts from Mexico, Uzbekistan China.

nd yet, it would be so easy for an advanced extra-strial civilization to leave a completely unambiguous ng card of their visit. For example, many nuclear icists believe that there is an 'island of stability' of ic nuclei, near a hypothetical superheavy atom with t 114 protons and about 184 neutrons. All chemical ents heavier than uranium (with 238 protons and ons in its nucleus) spontaneously decay in cosmically t periods of time. But there is reason to think that the ing between protons and neutrons is such that stable ents would be produced if nuclei having about 114

protons and 184 neutrons could be constructed. Suc
struction is just beyond our present technology, and
beyond the technology of our ancestors. A metal
containing such elements would be unambiguous e
of an advanced extraterrestrial civilization in our p
consider the element technetium, whose most stabl
has 99 protons and neutrons. Half of it radioactively
to other elements in about 200,000 years, half
remainder is gone in another 200,000 years, and so o
result, any technetium formed by stars with the
elements billions of years ago must all be gone by now
terrestrial technetium can only be of artificial origin
very name indicates. A technetium artifact could ha
one meaning. Similarly, there are common eleme
Earth that are immiscible; for example, aluminium an
If you melt them together, the lead, being consid
heavier, sinks to the bottom. The aluminium floats
top. However, in the zero g conditions of spaceflight
is no gravity in the melt to pull the heavier lead dow
exotic alloys such as Al/Pb can be produced. One
objectives of NASA's early Shuttle missions will be
out such alloying techniques. Any message written
aluminium/lead alloy and retrieved from an ancien
ization would certainly commend itself to our at
today.

It is also possible that the content rather than the m
of the message would clearly point to a science o
nology beyond the abilities of our ancestors: for ex
a vector calculus rendition of Maxwell's equations (
without magnetic monopoles), or a graphical represe
of the Planck black-body distribution for several di
temperatures, or a derivation of the Lorentz transfor
of special relativity. Even if the ancient civilization
not understand such writings, they might revere th
holy. But no cases of this sort have emerged – despit

arly a profitable market for tales of ancient or modern terrestrial astronauts. There have been debates on the y of magnesium samples from purported crashed s, but their purity was within the competence of Ameri- echnology at the time of the incident. A supposed star said to be retrieved (from memory) from the interior of ng saucer does not, as alleged, resemble the relative ions of the nearest stars like the Sun; in fact, a close ination shows it to be not much better than the 'star which would be produced if you took an old-fashioned pen and splattered a few blank pages with ink spots. one apparent exception, there are no stories sufficiently led to dispose of other explanations and sufficiently ate to portray correctly modern physics or astronomy prescientific or pretechnical people. The one exception remarkable mythology surrounding the star Sirius that d by the Dogon people of the Republic of Mali.

ere are at most a few hundred thousand Dogon alive , and they have been studied intensively by anthro- gists only since the 1930s. There are some elements of mythology that are reminiscent of the legends of the nt Egyptian civilization, and some anthropologists assumed a weak Dogon cultural connection with nt Egypt. The helical risings of Sirius were central to the tian calendar and used to predict the inundations of the The most striking aspects of Dogon astronomy have recounted by Marcel Griaule, a French anthropologist ing in the 1930s and 1940s. While there is no reason ubt Griaule's account, it is important to note that there earlier Western record of these remarkable Dogon beliefs and that all the information has been funnelled gh Griaule. The story has recently been popularized by tish writer, R. K. G. Temple.

contrast to almost all prescientific societies, the Dogon that the planets as well as the Earth rotate about their

axes and revolve about the Sun. This is a conclusio
can, of course, be achieved without high technolo
Copernicus demonstrated, but it is a very rare insight
the peoples of the Earth. It was taught, however, in
Greece by Pythagoras and by Philolaus, who perhap
in Laplace's words, 'that the planets were inhabited an
the stars were suns, disseminated in space, being them
centres of planetary systems'. Such teachings, among
variety of contradictory ideas, might be just an in
lucky guess.

The ancient Greeks believed there were only four ele
– earth, fire, water and air – from which all else wa
structed. Among the pre-Socratic philosophers there
those who made special advocacy for each one of
elements. If it had later turned out that the univers
indeed made more of one of these elements than an
we should not attribute remarkable prescience to th
Socratic philosopher who made the proposal. One of
was bound to be right on statistical grounds alone.
same way, if we have several hundred or several tho
cultures, each with its own cosmology, we should
astounded if, every now and then, purely by chance,
them proposes an idea that is not only correct bu
impossible for them to have deduced.

But, according to Temple, the Dogon go further.
hold that Jupiter has four satellites and that Satu
encircled by a ring. It is perhaps possible that indiv
of extraordinary eyesight under superb seeing cond
could, in the absence of a telescope, have observe
Galilean satellites of Jupiter and the rings of Saturn. B
is at the bare edge of plausibility. Unlike every astron
before Kepler, the Dogon are said to depict the p
moving correctly in elliptical, not circular, orbits.

More striking still is the Dogon belief about Siriu
brightest star in the sky. They contend that it has a da

sible companion star which orbits Sirius (and, Temple , in an elliptical orbit) once every fifty years. They state the companion star is very small and very heavy, made special metal called 'Sagala' which is not found on h.

he remarkable fact is that the visible star, Sirius A, does an extraordinary dark companion, Sirius B, which ts it in an elliptical orbit once each 50.04 ± 0.09 years. is B is the first example of a white dwarf star dis- red by modern astrophysics. Its matter is in a state d 'relativistically degenerate', which does not exist on h, and since the electrons are not bound to the nuclei in degenerate matter, it can properly be described as llic. Since Sirius A is called the Dog Star, Sirius B has etimes been dubbed 'The Pup'.

t first glance the Sirius legend of the Dogon seems to be best candidate evidence available today for past contact an advanced extraterrestrial civilization. As we begin a er look at this story, however, let us remember that the on astronomical tradition is purely oral, that it dates certainty only from the 1930s and that the diagrams written with sticks in sand. (Incidentally, there is some ence that the Dogon like to frame pictures with an se, and that Temple may be mistaken about the claim the planets and Sirius B move in elliptical orbits in gon mythology.)

hen we examine the full body of Dogon mythology we a very rich and detailed structure of legend – much er, as many anthropologists have remarked, than those eir near geographical neighbours. Where there is a rich y of legends there is, of course, a greater chance of an dental correspondence of one of the myths with a find- of modern science. A very spare mythology is much less y to make such an accidental concordance. But when we mine the rest of Dogon mythology, do we find other cases

hauntingly reminiscent of some unexpected find
modern science?

The Dogon cosmogony describes how the
examined a plaited basket, round at the mouth and
at the bottom. Such baskets are still in use in Mal
The Creator up-ended the basket and used it as a m
the creation of the world – the square base represe
sky and the round mouth the Sun. I must say th
account does not strike me as a remarkable antic
of modern cosmological thinking. In the Dogon re
tation of the creation of the Earth, the Creator implan
egg two pairs of twins, each pair comprised of a mal
female. The twins are intended to mature within the
fuse to become a single and 'perfect' androgynous
The Earth originates when one of the twins breaks fr
egg before maturation, whereupon the Creator sacrif
other twin in order to maintain a certain cosmic ha
This is a variegated and interesting mythology, but
not seem to be qualitatively different from many of th
mythologies and religions of humanity.

The hypothesis of a companion star to Sirius migh
followed naturally from the Dogon mythology, in
twins play a central role, but there does not seem to
explanation this simple about the period and density
companion of Sirius. The Dogon Sirius myth is too c
modern astronomical thinking and too precise q
tatively to be attributed to chance. Yet there
immersed in a body of more or less standard presc
legend. What can the explanation be? Is there any
that the Dogon or their cultural ancestors might a
have been able to see Sirius B and observe its period a
Sirius A?

White dwarfs such as Sirius B evolve from stars
red giants, which are very luminous and, it will be no su
to hear, red. Ancient writers of the first few centuri

ılly describe Sirius as red – certainly not its colour
y. In a conversation piece by Horace called 'Hoc
que Tiresia' (How to Get Rich Quickly) there is a
ation from an unspecified earlier work that says: 'The
log star's heat split the speechless statues.' As a result
ese less than compelling ancient sources there has been a
t temptation among astrophysicists to consider the
bility that the white dwarf Sirius B was a red giant in
rical times and visible with the naked eye, completely
ıping the light of Sirius A. In that case perhaps there
ı slightly later time in the evolution of Sirius B when
rightness was comparable to that of Sirius A, and the
ve motion of the two stars about each other could be
rned with the unaided eye. But the best recent informa-
from the theory of stellar evolution suggests that there
ly is not enough time for Sirius B to have reached its
nt white dwarf state if it had been a red giant a few
ıries before Horace. What is more, it would seem extra-
ıary that no one except the Dogon noticed these two
circling each other every fifty years, each alone being
of the brightest stars in the sky. There was an extremely
petent school of observational astronomers in Meso-
mia and in Alexandria in the preceding centuries – to
othing of the Chinese and Korean astronomical schools
l it would be astonishing if they had noticed anything.*
r only alternative, then, to believe that representatives
extraterrestrial civilization have visited the Dogon or
ancestors?
he Dogon have knowledge impossible to acquire with-
the telescope. The straightforward conclusion is that

he ancient Egyptian phrase for the planet Mars translates to 'the red
', Horus being the imperial falcon deity. Thus Egyptian astronomy
remarkable coloration in celestial objects. But the description of
mentions nothing notable about its colour.

they had contact with an advanced technical civ
The only question is, which civilization – extraterr
European? Far more credible than an ancient ext
trial educational foray among the Dogon mig
comparatively recent contact with scientifically
Europeans who conveyed to the Dogon the rem
European myth of Sirius and its white dwarf comp
myth that has all the superficial earmarks of a sp
inventive tall story. Perhaps the Western contact ca
a European visitor to Africa, or from the local
schools, or perhaps from contacts in Europe b
Africans inducted to fight for the French in World

The likelihood that these stories arise from conta
Europeans rather than extraterrestrials has been incre
a recent astronomical finding: a Cornell University r
team led by James Elliot, employing a high-altitude a
observatory over the Indian Ocean, discovered in 19
the planet Uranus is surrounded by rings – a findin
hinted at by ground-based observations. Advanced
terrestrial beings viewing our solar system upon ap
to Earth would have little difficulty discovering th
of Uranus. But European astronomers in the ninetee
early twentieth centuries would have had nothing to
this regard. The fact that the Dogon do not talk of a
planet beyond Saturn with rings suggests to me th
informants were European, not extraterrestrial.

In 1844 the German astronomer F. W. Bessel disc
that the long-term motion of Sirius itself (Sirius A) w
straight but, rather, wavy against the background o
distant stars. Bessel proposed that there was a dar
panion to Sirius whose gravitational influence was pro
the observed sinusoidal motion. Since the period
wiggle was fifty years, Bessel deduced that the dar
panion had a fifty-year period in the joint motion of S
and B about their common centre of mass.

ghteen years later Alvan G. Clark, during the testing of
v 18½-inch refracting telescope, accidentally discovered
ompanion, Sirius B, by direct visual observation. From
elative motions, Newtonian gravitational theory per-
us to estimate the masses of Sirius A and B. The
panion turns out to have a mass just about the same
e Sun's. But Sirius B is almost ten thousand times
er than Sirius A, even though their masses are about
ame and they are just the same distance from the
n. These facts can be reconciled only if Sirius B has a
smaller radius or a much lower temperature. But in
ate nineteenth century it was believed by astronomers
stars of the same mass had approximately the same
erature, and by the turn of the century it was widely
that the temperature of Sirius B was not remarkably
Spectroscopic observations by Walter S. Adams in
confirmed this contention. Hence, Sirius B must be very
.. We know today that it is only as big as the Earth.
use of its size and colour it is called a white dwarf. But
ius B is much smaller than Sirius A, its density must
ry much greater. Accordingly, the concept of Sirius B as
tremely dense star was widely held in the first few
des of this century.

e peculiar nature of the companion of Sirius was
sively reported in books and in the press. For example,
r Arthur Stanley Eddington's book *The Nature of the
ical World*, we read: 'Astronomical evidence seems to
practically no doubt that in the so-called *white dwarf*
the density of matter far transcends anything of which
ave terrestrial experience; in the Companion of Sirius,
xample, the density is about a ton to the cubic inch.
condition is explained by the fact that the high tempera-
and correspondingly intense agitation of the material
ks up (ionises) the outer electron system of the atoms,
at the fragments can be packed much more closely

together.' Within a year of its 1928 publication, this saw ten reprintings in English. It was translated into languages, including French. The idea that white d were made of electron degenerate matter had been pro by R. H. Fowler in 1925 and quickly accepted. On the hand, the proposal that white dwarfs were made of tivistically degenerate' matter was first made in the p 1934 to 1937, in Great Britain, by the Indian astroph S. Chandrasekhar; the idea was greeted with subst scepticism by astronomers who had not grown up quantum mechanics. One of the most vigorous sceptic Eddington. The debate was covered in the scientific and was accessible to the intelligent layman. All thi occurring just before Griaule encountered the Dogon legend.

In my mind's eye I picture a Gallic visitor to the D people, in what was then French West Africa, in the part of this century. He may have been a diploma explorer, an adventurer or an early anthropologist. people – for example, Richard Francis Burton – w West Africa many decades earlier. The conversation to astronomical lore. Sirius is the brightest star in th The Dogon regale the visitor with their Sirius myth Then, smiling politely, expectantly, they inquire of visitor what *his* Sirius myths might be. Perhaps he before answering to a well-worn book in his baggage white dwarf companion of Sirius being a current nomical sensation, the traveller exchanges a specta myth for a routine one. After he leaves, his accou remembered, retold, and eventually incorporated int corpus of Dogon mythology – or at least into a coll branch (perhaps filed under 'Sirius myths, bleached pe account'). When Marcel Griaule makes mythologic quiries in the 1930s and 1940s, he has his own Euro Sirius myth played back to him.

ULL-CYCLE RETURN of a myth to its culture of origin
gh an unwary anthropologist might sound unlikely if
were not so many examples of it in anthropological
here recount a few cases:

he first decade of the twentieth century a neophyte
pologist was collecting accounts of ancient traditions
Native American populations in the Southwest. His
n was to write down the traditions, almost exclusively
before they vanished altogether. The young Native
cans had already lost appreciable contact with their
ge, and the anthropologist concentrated on elderly
ers of the tribe. One day he found himself sitting
e a hogan with an aged but lively and cooperative
hant.

il me about the ceremonies of your ancestors at the
of a child.'

st one moment.'

old Indian slowly shuffled into the darkened depths of
ogan. After a fifteen-minute interval he reappeared
remarkably useful and detailed description of post-
n ceremonials, including rituals connected with breach
tation, afterbirth, umbilical cord, first breath and first
ncouraged and writing feverishly, the anthropologist
natically went through the full list of rites of passage,
ing puberty, marriage, childbearing and death. In each
he informant disappeared into the hogan only to
e a quarter of an hour later with a rich set of answers.
nthropologist was astonished. Could, he wondered,
be a yet older informant, perhaps infirm and bed-
n, within the hogan? Eventually he could resist no
and summoned the courage to ask his informant what
l at each retreat into the hogan. The old man smiled,
rew for the last time, and returned clutching a well-
bed volume of the *Dictionary of American Ethno-*
y, which had been compiled by anthropologists in the

previous decade. The poor white man, he m
thought, is eager, well-meaning and ignorant. He
have a copy of this marvellous book which con
traditions of my people. I shall tell him what it sa

My other two stories recount the adventures of a
ordinary physician, Dr. D. Carleton Gajdusek,
many years has studied kuru, a rare viral disease,
the inhabitants of New Guinea. For this work he
recipient of the 1976 Nobel Prize for Medicine. I ar
ful to Dr. Gajdusek for taking the trouble to ch
memory of his stories, which I first heard from hi
years ago. New Guinea is an island on which mour
terrain separates – in a manner similar to but mo
pletely than the mountains of ancient Greece – on
people from another. As a result there is a great pr
and variety of cultural traditions.

In the spring of 1957 Gajdusek and Dr. Vincent
medical officer with the Public Health Service of w
then called the Territory of Papua and New
travelled with an Australian administrative patrol
from the Purosa Valley through the ranges of the
Fore cultural and linguistic-group region to the vi
Agakamatasa on an exploratory visit into 'uncon
territory'. Stone implements were still in use, an
remained a tradition of cannibalism within one's ow
group. Gajdusek and his party found cases of kuru
is spread by cannibalism (but most often not throu
digestive tract), in this most remote of the Sout
villages. They decided to spend a few days, moving i
of the large and traditional *wa'e*, or men's hous
music from one of which, incidentally, was sent to t
on the Voyager phonograph record). The windowles
doored, smokey thatched house was partitioned so t
visitors could neither stand erect nor stretch out.
divided into many sleeping compartments, each with

fire, around which men and boys would huddle in
ɔs to sleep and keep warm during the cold nights at
evation of more than 6,000 feet, an altitude higher
Denver. To accommodate their visitors, the men and
gleefully tore out the interior structure of half of the
ıonial men's house, and during two days and nights
uring rain Gajdusek and his companions were house-
d on a high, windswept, cloud-covered ridge. The
g Fore initiates wore bark strands braided into their
which was covered with pig grease. They wore huge
pieces, the penises of pigs as armbands, and the
alia of opossums and tree-climbing kangaroos as
ants around their necks.

e hosts sang their traditional songs all through the first
and on through the following rainy day. In return, 'to
nce our rapport with them,' as Gajdusek says, 'we
ı to sing songs in exchange – among them such Russian
s as "Otchi chornye", and "Moi kostyor v tumane
" . . .' This was received very well, and the Agakama-
villagers requested many dozens of repetitions in the
y South Fore longhouse to the accompaniment of the
ng rainstorm.

me years later Gajdusek was engaged in the collection
ligenous music in another part of the South Fore region
sked a group of young men to run through their reper-
of traditional songs. To Gajdusek's amazement and
ement, they produced a somewhat altered but still
ly recognizable version of 'Otchi chornye'. Many of the
rs apparently thought the song traditional, and later
Gajdusek found the song imported even farther afield,
none of the singers having any idea of its source.

e can easily imagine some sort of world ethnomusi-
gy survey coming to an exceptionally obscure part of
Guinea and discovering that the natives had a tradi-
l song which sounded in rhythm, music and words

remarkably like 'Otchi chornye'. If they were to belie
no previous contact of Westerners with these peop
occurred, a great mystery could be posited.

Later that same year Gajdusek was visited by
Australian physicians, eager to understand the rema
findings about the transmission of kuru from pati
patient by cannibalism. Gajdusek described the theo
the origin of many diseases held by the Fore people
did *not* believe that illnesses were caused by the spirits
dead or that malicious deceased relatives, jealous
living, inflicted disease on those of their surviving ki
who offended them, as the pioneering anthrope
Bronislaw Malinowski had recounted for the coastal p
of Melanesia. Instead, the Fore attributed most di
to malicious sorcery, which any offended and ave
male, young or old, could execute without the aid of sp
trained sorcerers. There was a special sorcery expla
for kuru, but also for chronic lung disease, leprosy,
and so on. These beliefs had been long-establishe
firmly held, but as the Fore people witnessed yaws yi
entirely to the penicillin injections of Gajdusek a
group, they quickly agreed that the sorcery explanat
yaws was in error and abandoned it; it has never resu
in subsequent years. (I wish Westerners would be as qu
abandon obsolete or erroneous social ideas as the F
New Guinea.) Modern treatment of leprosy caus
sorcery explanation to disappear as well, although
slowly, and the Fore people today laugh at these bac
early opinions on yaws and leprosy. But the traditiona
on the origin of kuru have maintained themselves, sin
Westerners have been unable to cure or explain, in a m
satisfactory to them, the origin and nature of this d
Thus, the Fore people remain intensely sceptical of W
explanations for kuru and retain firmly their view
malicious sorcery is the cause.

ne of the Australian physicians, visiting an adjacent
ge with one of Gajdusek's native informants as transla-
spent the day examining kuru patients and independ-
acquiring information. He returned the same evening
form Gajdusek that he was mistaken about people not
ving in the spirits of the dead as the cause of disease,
that he was further in error in holding that they had
ıdoned the idea of sorcery as the cause of yaws. The
ole held, he continued, that a dead body could become
ible and that the unseen spirit of the dead person could
r the skin of a patient at night through an imperceptible
k, and induce yaws. The Australian's informant had
sketched with a stick in the sand the appearance of
e ghostly beings. They carefully drew a circle and a
squiggly lines within. Outside the circle, they explained,
as black; inside the circle, bright – a sand portrait of
evolent and pathogenic spirits.

pon inquiry of the young translator, Gajdusek dis-
red that the Australian physician had conversed with
e of the older men of the village who were well known
ajdusek and who were often his house and laboratory
ts. They had attempted to explain that the shape of
'germ' producing yaws was spiral – the spirochete form
had seen many times through Gajdusek's dark-field
roscope. They had to admit it was invisible – it could
een only through the microscope – and when pressed
he Australian physician on whether this 'represented'
dead person, they had to admit that Gajdusek had
ssed that it could be caught from close contact with
s lesions, as, for example, by sleeping with a person with
s.

can well remember the first time I looked through a
roscope. After focusing my eyes up near the ocular only
xamine my eyelashes, and then peering further into the
h-black interior of the barrel, I finally managed to look

straight down the microscope tube to be dazzle
illuminated disc of light. It takes a little while for t
train itself to examine what is in the disc. Ga
demonstration to the Fore people was so powerfu
all, the alternatives entirely lacked so concrete a reali
many accepted his story, even apart from his ability
the disease with penicillin. Perhaps some conside
spirochetes in the microscope an amusing example o
man myth and minor magic, and when another wh
arrived querying the origin of disease, they politely r
to him the idea they believed he would be comfortab
Had Western contact with the Fore people ceased
years; it seems to me entirely possible that a future
would discover to his astonishment that the Fore
somehow had knowledge of medical microbiology,
their largely pretechnological culture.

All three of these stories underline the almost ine
problems encountered in trying to extract from a 'pri
people their ancient legends. Can you be sure that
have not come before you and destroyed the pristi
of the native myth? Can you be sure that the nati
not humouring you or pulling your leg? Bronislaw Ma
ski thought he had discovered a people in the Tro
Islands who had not worked out the connection b
sexual intercourse and childbirth. When asked how c
were conceived, they supplied him with an elaborate
structure prominently featuring celestial interv
Amazed, Malinowski objected that was not how
done at all, and supplied them instead with the ver
popular in the West today – including a nine-month
tion period. 'Impossible,' replied the Melanesians. '
not see that woman over there with her six-month-ol
Her husband has been on an extended voyage to a
island for two years.' Is it more likely that the Mela
were ignorant of the begetting of children or th

gently chiding Malinowski? If some peculiar-looking
er came into my town and asked *me* where babies
from, I'd certainly be tempted to tell him about storks
ıbbages. Prescientific people are people. Individually
ıre as clever as we are. Field interrogation of in-
nts from a different culture is not always easy.

ɔnder if the Dogon, having heard from a Westerner an
rdinarily inventive myth about the star Sirius – a star
.y important in their own mythology – did not care-
ɔlay it back to the visiting French anthropologist. Is
ɔt more likely than a visit by extraterrestrial space-
to ancient Egypt, with one cluster of hard scientific
:edge, in striking contradiction to common sense,
ved by oral tradition, over the millennia, and only in
Africa?

:re are too many loopholes, too many alternative ex-
:ions for such a myth to provide reliable evidence of
xtraterrestrial contact. If there are extraterrestrials, I
it much more likely that unmanned planetary space-
ınd large radiotelescopes will prove to be the means of
letection.

CHAPTER 7

VENUS AND DR. VELIKOVSKY

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* * *

When the movement of the comets is considered and we on the laws of gravity, it will be readily perceived th approach to the Earth might there cause the most woeful bring back the universal deluge, or make it perish in a de fire, shatter it into small dust, or at least turn it from it drive away its Moon, or, still worse, the Earth itself outs orbit of Saturn, and inflict upon us a winter several ce long, which neither men nor animals would be able t The tails even of comets would not be unimportant phen if the comets in taking their departure left them in whol part in our atmosphere.

J. H. LAMBERT,
Cosmologische Briefe über die Einrichtung des Weltbaues (1761)

However dangerous might be the shock of a comet, it m so slight, that it would only do damage at the part of the where it actually struck; perhaps even we might cry quits i one kingdom were devastated, the rest of the Earth w enjoy the rarities which a body which came from so far bring to it. Perhaps we should be very surprised to fin the debris of these masses that we despised were formed and diamonds; but who would be the most astonished, we comet-dwellers, who would be cast on our Earth? What s beings each would find the other!

MAUPERTUIS,
Lettre sur la comète (1752)

ISTS, like other human beings, have their hopes and their passions and despondencies – and their strong ons may sometimes interrupt the course of clear think- d sound practice. But science is also self-correcting. ıost fundamental axioms and conclusions may be ıged. The prevailing hypotheses must survive con- tion with observation. Appeals to authority are im- sible. The steps in a reasoned argument must be t for all to see. Experiments must be reproducible.

history of science is full of cases where previously ed theories and hypotheses have been entirely over- ı, to be replaced by new ideas that more adequately ı the data. While there is an understandable psycho- inertia – usually lasting about one generation – such tions in scientific thought are widely accepted as a ary and desirable element of scientific progress. l, the reasoned criticism of a prevailing belief is a to the proponents of that belief; if they are incapable ending it, they are well advised to abandon it. This ıestioning and error-correcting aspect of the scientific d is its most striking property, and sets it off from many areas of human endeavour where credulity is the rule. idea of science as a method rather than as a body of edge is not widely appreciated outside of science, or l in some corridors inside of science. For this reason I ome of my colleagues in the American Association for dvancement of Science have advocated a regular set cussions at the annual AAAS meeting of hypotheses re on the borderlines of science and that have attracted ıntial public interest. The idea is not to attempt to settle ssues definitively, but rather to illustrate the process of ned disputation, to show how scientists approach a em that does not lend itself to crisp experimentation, ınorthodox in its interdisciplinary nature, or otherwise s strong emotions.

Vigorous criticism of new ideas is a comm
science. While the style of the critique may va
character of the critic, overly polite criticism ben
the proponents of new ideas nor the scientific
Any substantive objection is permissible and e
the only exception being that *ad hominem* atta
personality or motives of the author are exclud
not matter what reason the proponent has for ad
ideas or what prompts his opponents to criticiz
that matters is whether the ideas are right
promising or retrogressive.

For example, here is a summary – of a ty
unusual but not extremely rare – of a paper sub
the scientific journal *Icarus*, by a qualified referee
opinion of this reviewer that this paper is
unacceptable for publication in *Icarus*. It is bas
sound scientific research, and at best it is inc
speculation. The author has not stated his assump
conclusions are unclear, ambiguous and witho
credit is not given to related work; the figures a
are unclearly labelled; and the author is obviously u
with the most basic scientific literature . . .' The re
goes on to justify his remarks in detail. The p
rejected for publication. Such rejections are c
recognized as a boon to science as well as a favo
author. Most scientists are accustomed to receivi
what milder) referees' criticisms every time they
paper to a scientific journal. Almost always the crit
helpful. Often a paper revised to take these criti
account is subsequently accepted for publicatio
other example of forthright criticism in the planeta
literature, the interested reader might wish t
'Comments on *The Jupiter Effect*' by J. Meeus (1
the commentary on it in *Icarus*.

* Citations to references in this chapter are given at the end

orous criticism is more constructive in science than in other areas of human endeavour because in science are adequate standards of validity that can be agreed by competent practitioners the world over. The objec- of such criticism is not to suppress but rather to rage the advance of new ideas: those that survive a firm cal scrutiny have a fighting chance of being right, or at useful.

ONS IN THE scientific community have run very high on ue of Immanuel Velikovsky's work, especially his first *Worlds in Collision*, published in 1950. I know that scientists were irked because Velikovsky was com- to Einstein, Newton, Darwin and Freud by New literati and an editor of *Harper's*, but this pique arises the frailty of human nature rather than the judgment scientist. The two together often inhabit the same dual. Others were dismayed at the use of Indian, se, Aztec, Assyrian or Biblical texts to argue for nely heterodox views in celestial mechanics. Also, I ct, not many physicists or celestial mechanicians are rtably fluent in such languages or are familiar with texts.

own view is that no matter how unorthodox the ning process or how unpalatable the conclusions, there excuse for any attempt to suppress new ideas – least by scientists. Therefore I was very pleased that the S held a discussion on *Worlds in Collision*, in which ovsky took part.

reading the critical literature in advance, I was sur- l at how little of it there is and how rarely it approaches entral points of Velikovsky's thesis. In fact, neither itics nor the proponents of Velikovsky seem to have him carefully, and I even seem to find some cases Velikovsky has not read Velikovsky carefully. Per-

haps the publication of most of the AAAS
(Goldsmith, 1977) as well as the present chapter
pal conclusions of which were presented at the
will help to clarify the issues.

In this chapter I have done my best to analyse c
thesis of *Worlds in Collision*, to approach the pr
on Velikovsky's terms and on mine – that is, to
in mind the ancient writings that are the fo
argument, but at the same time to confront his c
with the facts and the logic I have at my comm

Velikovsky's principal thesis is that major ev
history of both the Earth and the other planets i
system have been dominated by catastrophism r
by uniformitarianism. These are fancy words used
gists to summarize a major debate they had
infancy of their science which apparently c
between 1785 and 1830, in the work of James H
Charles Lyell, in favour of the uniformitarians.
names and the practices of these two sects evok
theological antecedents. A uniformitarian holds
forms on Earth have been produced by process
observe to be operating today, provided they op
immense vistas of time. A catastrophist holds th
number of violent events, occupying much short
of time, are adequate. Catastrophism began larg
minds of those geologists who accepted a literal i
tion of the Book of Genesis, and in particular th
of the Noahic flood. It is clearly no use argui
the catastrophist viewpoint to say that we have
such a catastrophe in our lifetimes. The hypothes
only rare events. But if we can show that there is
time for processes we can all observe operating
produce the landform or event in question, then
least no necessity for the catastrophist hypot
viously both uniformitarian and catastrophic pro

been at work – and almost certainly both were – in
istory of our planet.

ikovsky holds that in the relatively recent history of the
there has been a set of celestial catastrophes, near-
ons with comets, small planets and large planets. There
thing absurd in the possibility of cosmic collisions.
nomers in the past have not hesitated to invoke
ions to explain natural phenomena. For example,
r and Baade (1951) proposed that extragalactic radio
es may be produced by the collisions of whole galaxies,
ining hundreds of billions of stars. This thesis has
been abandoned, not because cosmic collisions are
nkable, but because the frequency and properties of
collisions do not match what is now known about
radio sources. A still popular theory of the energy
e of quasars is multiple stellar collisions at the centres
laxies – where, in any case, catastrophic events must
mmon.

llisions and catastrophism are part and parcel of
rn astronomy, and have been for many centuries (see
igraphs at the beginning of this chapter). For example,
e early history of the solar system, when there were
ably many more objects about than there are now –
ding objects on very eccentric orbits – collisions may
been frequent. Lecar and Franklin (1973) investigate
reds of collisions occurring in a period of only a few
and years in the early history of the asteroid belt, to
rstand the present configuration of this region of the
system. In another paper, entitled 'Cometary Col-
s and Geological Periods', Harold Urey (1973) investi-
a range of consequences, including the production of
quakes and the heating of the oceans, which might
d the collision with the Earth of a comet of average
of about 10^{18} grams. The Tunguska event of 1908, in
h a Siberian forest was levelled, is often attributed

to the collision with the Earth of a small comet. T
surfaces of Mercury, Mars, Phobos, Deimos and
bear eloquent testimony to the fact that there
abundant collisions during the history of the sol
There is nothing unorthodox about the idea of co
trophes, and this is a view that has been commo
system physics at least back to the late-nineteent
studies of the lunar surface by G. K. Gilbert,
director of the US Geological Survey.

What, then, is all the furore about? It is abou
scale and the adequacy of the purported eviden
4.6 billion-year history of the solar system, many
must have occurred. But have there been major co
the last 3,500 years, and can the study of ancien
demonstrate such collisions? That is the nub of t

VELIKOVSKY has called attention to a wide range
and legends, held by diverse peoples, separated
distances, which stories show remarkable simila
concordances. I am not expert in the cultures or
of any of these peoples, but I find the concate
legends Velikovsky has accumulated stunning. It is
some experts in these cultures are less impress
remember vividly discussing *Worlds in Collision* w
tinguished professor of Semitics at a leading univ
said something like 'The Assyriology, Egyptology
scholarship and all of that Talmudic and Midras
is, of course, nonsense; but I was impressed b
tronomy.' I had rather the opposite view. But let
swayed by the opinions of others. My own positi
if even 20 percent of the legendary concorda
Velikovsky produces are real, there is something i
to be explained. Furthermore, there is an impress
of cases in the history of archaeology – from
Schliemann at Troy to Yigael Yadin at Masada

escriptions in ancient writings have subsequently been
ated as fact.

w, if a variety of widely separated cultures share what is
bly the same legend, how can this be understood?
: seem to be four possibilities: common observation,
ion, brain wiring and coincidence. Let us consider
in turn.

mmon Observation: One explanation is that the cultures
estion all witnessed a common event and interpreted
he same way. There may, of course, be more than one
of what this common event was.

ffusion: The legend originated within one culture only,
uring the frequent and distant migrations of mankind,
tally spread with some changes among many appar-
diverse cultures. A trivial example is the Santa Claus
d in America which evolved from the European Saint
olas (Claus is short for Nicholas in German), the patron
of children, and which ultimately is derived from pre-
tian tradition.

ain Wiring: A hypothesis sometimes also known as
l memory or the collective unconscious. It holds that
are certain ideas, archetypes, legendary figures, and
s that are intrinsic to human beings at birth, perhaps
e same way that a newborn baboon knows to fear a
e, and a bird raised in isolation from other birds knows
to build a nest. It is apparent that if a tale derived from
rvation or from diffusion resonated with the 'brain
g', it is more likely to be culturally retained.

incidence: Purely by chance two independently derived
ds may have similar content. In practice, this hypo-
s fades into the brain-wiring hypothesis.

E ARE TO ASSESS critically such apparent concordances,
are some obvious precautions that must first be taken.
he stories really say the same thing or have the same

essential elements? If they are interpreted as due to common observations, do they date from the same period? Can we exclude the possibility of physical contact between representatives of the cultures in question in or before the epoch under discussion? Velikovsky is clearly opting for the common-observation hypothesis, but he seems to dismiss the diffusion hypothesis far too casually; for example, he says (page 303*): 'How could unusual motifs of folklore reach isolated islands, where the aborigines do not have any means of crossing the sea?' I am not sure which islands and which aborigines Velikovsky refers to here, but it is apparent that the inhabitants of an island had to have got there somehow. I do not think that Velikovsky believes in a separate creation in the Gilbert and Ellice Islands, say. For Polynesia and Melanesia there is now extensive evidence of abundant sea voyages of lengths of many thousands of kilometres within the last millennium, and probably much earlier (Dodd, 1972).

Or how, for example, would Velikovsky explain the fact that the Toltec name for 'god' seems to have been *teo*, as in the great pyramid city of Teotihuacán ('City of the Gods') near present-day Mexico City, where it is called San Juan Teotihuacán? There is no common celestial event that could conceivably explain this concordance. Toltec and Nahuatl are non-Indoeuropean languages, and it seems unlikely that the *word* for 'god' would be wired into all human brains. Yet *teo* is a clear cognate of the common Indoeuropean root for 'god', preserved, among other places, in the words 'deity' and 'theology'. The preferred hypotheses in this case are coincidence or diffusion. There is some evidence for pre-Columbian contact between the Old and New Worlds. But coincidence is also not to be taken lightly: if we compare two languages, each with tens of thousands

* The page numbers to the canonical English-language edition (Velikovsky, 1950).

of words, spoken by human beings with identical larynxes, tongues and teeth, it should not be surprising if a few words are coincidentally identical. Likewise, we should not be surprised if a few elements of a few legends are coincidentally identical. But I believe that *all* of the concordances Velikovsky produces can be explained away in this manner.

Let us take an example of Velikovsky's approach to this question. He points to certain concordant stories, directly or vaguely connected with celestial events, that refer to a witch, a mouse, a scorpion or a dragon (pages 77, 264, 305, 306, 310). His explanation: divers comets, upon close approach to the Earth, were tidally or electrically distorted and gave the form of a witch, a mouse, a scorpion or a dragon, clearly interpretable as the same animal to culturally isolated peoples of very different backgrounds. No attempt is made to show that such a clear form – for example, a woman riding a broomstick and topped by a pointed hat – could have been produced in this way, even if we grant the hypothesis of a close approach to the Earth by a comet. Our experience with Rorschach and other psychological projective tests is that different people see the same nonrepresentational image in different ways. Velikovsky even goes so far as to believe that a close approach to the Earth by 'a star' he evidently identifies with the planet Mars so distorted it that it took on the clear shape page 264) of lions, jackals, dogs, pigs and fish; and in his opinion this explains the worship of animals by the Egyptians. This is not very impressive reasoning. We might just as well assume that the whole menagerie was capable of independent flight in the second millennium B.C. and be done with it. A much more likely hypothesis is diffusion. Indeed, I have in a different context spent a fair amount of time studying the dragon legends on the planet Earth, and I am impressed by how different these mythical beasts, all called dragons by Western writers, really are.

As another example, consider the argument of Chapter 8, Part 2 of *Worlds in Collision*. Velikovsky claims a world-wide tendency in ancient cultures to believe at various times that the year has 360 days, that the month has thirty-six days, and that the year has ten months. Velikovsky offers no justification in physics for this, but argues that ancient astronomers could hardly have been so poor at their trade as to slip five days each year or six days each lunation. Fairly soon the night would be brilliant with moonlight at the astrologically official new moon, snowstorms would be falling in July, and the astrologers would be hung by their ears. Having had some experience with modern astronomers, I am not as confident as Velikovsky is in the unerring computational precision of ancient astronomers. Velikovsky proposes that these aberrant calendrical conventions reflect real changes in the length of the day, month and/or year – and that they are evidence of close approaches to the Earth-Moon system by comets, planets and other celestial visitors.

There is an alternative explanation, which derives from the fact that there are not a whole number of lunations in a solar year, nor a whole number of days in a lunation. These incommensurabilities will be galling to a culture that has recently invented arithmetic but has not yet got as far as large numbers or fractions. As an inconvenience, these incommensurabilities are felt even today by religious Muslims and Jews who discover that Ramadan and Passover, respectively, occur from year to year on rather different days of the solar calendar. There is a clear whole-number chauvinism in human affairs, most easily discerned in discussing arithmetic with four-year-olds; and this seems to be a much more plausible explanation of these calendrical irregularities, if they existed.

Three hundred and sixty days a year provides an obvious (temporary) convenience for a civilization with base-60 arithmetic, as the Sumerian, Akkadian, Assyrian and Baby-

lonian cultures. Likewise, thirty days per month or ten months per year might be attractive to enthusiasts of base-10 arithmetic. I wonder if we do not see here an echo of the collision between chauvinists of base-60 arithmetic and chauvinists of base-10 arithmetic, rather than a collision of Mars with Earth. It is true that the tribe of ancient astrologers may have been dramatically depleted as the various calendars rapidly slipped out of phase, but that was an occupational hazard, and at least it removed the mental agony of dealing with fractions. In fact, sloppy quantitative thinking appears to be the hallmark of this whole subject.

An expert on early time-reckoning (Leach, 1957) points out that in ancient cultures the first eight or ten months of the year are named, but the last few months, because of their economic unimportance in an agricultural society, are not. Our month December, named after the Latin *decem*, means the tenth, not the twelfth, month. (September = seventh, October = eighth, November = ninth, as well.) Because of the large numbers involved, prescientific peoples characteristically do not count days of the year, although they are assiduous in counting months. A leading historian of ancient science and mathematics, Otto Neugebauer (1957) remarks that, both in Mesopotamia and in Egypt, two separate and mutually exclusive calendars were maintained: a civil calendar whose hallmark was computational convenience, and a frequently updated agriculture calendar - messier to deal with, but much closer to the seasonal and astronomical realities. Many ancient cultures solved the two-calendar problem by simply adding a five-day holiday on at the end of the year. I hardly think that the existence of 360-day years in the calendrical conventions of prescientific peoples is compelling evidence that then there really were 360 rather than $365\frac{1}{4}$ rotations in one revolution of Earth about the Sun.

This question can, in principle, be resolved by examining

coral growth rings, which are now known to show with some accuracy the number of days per month and the number of days per year, the former only for intertidal corals. There appears to be no sign of major excursions in recent times from the present number of days in a lunation or a year, and the gradual shortening (not lengthening) of the day and the month with respect to the year as we go back in time is found to be consistent with tidal theory and the conservation of energy and angular momentum within the Earth-Moon system, without appeal to cometary or other exogenous intervention.

Another problem with Velikovsky's method is the suspicion that vaguely similar stories may refer to quite different periods. This question of the synchronism of legends is almost entirely ignored in *Worlds in Collision*, although it is treated in some of Velikovsky's later works. For example (page 31), Velikovsky notes that the idea of four ancient ages terminated by catastrophe is common to Indian as well as to Western sacred writing. However, in the *Bhagavad Gita* and in the Vedas, widely divergent numbers of such ages, including an infinity of them, are given; but, more interesting, the duration of the ages between major catastrophes is specified (see, for example, Campbell, 1974) as billions of years. This does not match very well Velikovsky's chronology, which requires hundreds or thousands of years. Here Velikovsky's hypothesis and the data that purport to support it differ by a factor of about a million. Or (page 91) vaguely similar discussions of vulcanism and lava flows in Greek, Mexican and Biblical traditions are quoted. There is no attempt made to show that they refer to even approximately comparable times and, since lava has flowed in historical times in all three areas, no common exogenous event is necessary to interpret such stories.

Despite copious references, there also seem to me to be a

arge number of critical and undemonstrated assumptions n Velikovsky's argument. Let me mention just a few of hem. There is the very interesting idea that any mythologi-al references by any people to any god that also corresponds o a celestial body represents in fact a direct observation of that celestial body. It is a daring hypothesis, although am not sure what one is to do with Jupiter appearing s a swan to Leda, and as a shower of gold to Danaë. On page 247 the hypothesis that gods and planets are identical is used to date the time of Homer. In any case, when Hesiod and Homer refer to Athena being born full-grown rom the head of Zeus, Velikovsky takes Hesiod and Homer t their word and assumes that the celestial body Athena vas ejected by the planet Jupiter. But what *is* the celestial body Athena? Repeatedly it is identified with the planet Venus (Part 1, Chapter 9, and many other places in the ext). One would scarcely guess from reading *Worlds in Collision* that the Greeks characteristically identified Aphrodite with Venus, and Athena with no celestial body whatever. What is more, Athena and Aphrodite were 'con-emporaneous' goddesses, both being born at the time Zeus vas king of the gods. On page 251 Velikovsky notes that Lucian 'is unaware that Athene is the goddess of the planet Venus'. Poor Lucian seems to be under the misconception hat Aphrodite is the goddess of the planet Venus. But in he footnote on page 361 there appears to be a slip, and here Velikovsky for the first and only time uses the form Venus (Aphrodite)'. On page 247 we hear of Aphrodite, he goddess of the Moon. Who, then, was Artemis, the ister of Apollo the Sun, or, earlier, Selene? There may be good justification, for all I know, in identifying Athena with Venus, but it is far from the prevailing wisdom either now or two thousand years ago, and it is central to Velikovsky's argument. It does not increase our confidence n the presentation of less familiar myths when the

celestial identification of Athena is glossed over so lightly.

Other critical statements which are given extremely inadequate justification, and which are central to one or more of Velikovsky's major themes, are: the statement (page 283) that 'Meteroites, when entering the earth's atmosphere make a frightful din', when they are generally observed to be silent; the statement (page 114) that 'a thunderbolt, when striking a magnet, reverses the poles of the magnet'; the translation (page 51) of 'Barad' as meteorites; and the contention (page 85) 'as is known, Pallas was another name for Typhon'. On page 179 a principle is implied that when two gods are hyphenated in a joint name, it indicates an attribute of a celestial body – as, for example, Ashteroth-Karnaim, a horned Venus, which Velikovsky interprets as a crescent Venus and evidence that Venus was once close to Earth to have its phases discernible to the naked eye. But what does this principle imply, for example, for the god Ammon-Ra? Did the Egyptians see the sun (Ra) as a ram (Ammon)?

There is a contention (page 63) that instead of the tenth plague of Exodus killing the 'first born' of Egypt, what is intended is the killing of the 'chosen'. This is a rather serious matter and at least raises the suspicion that where the Bible is inconsistent with Velikovsky's hypothesis Velikovsky retranslates the Bible. The foregoing queries may all have simple answers, but the answers are not to be found easily in *Worlds in Collision*.

I do not mean to suggest that all of Velikovsky's legendary concordances and ancient scholarship are similarly flawed, but many of them seem to be, and the remainder may well have alternative, for example diffusionist, origins.

With the situation in legend and myth as fuzzy as this any corroboratory evidence from other sources would be welcomed by those who support Velikovsky's argument. I am struck by the absence of any confirming evidence in art

There is a wide range of paintings, bas-reliefs, cylinder seals and other *objets d'art* produced by humanity and going back to at least 10,000 B.C. They represent all of the subjects, especially mythological subjects, important to the cultures that created them. Astronomical events are not uncommon in such works of art. Recently (Brandt, *et al.*, 1974), impressive evidence has been uncovered in cave paintings in the American Southwest of contemporary observations of the Crab Supernova event of the year 1054, which was also recorded in Chinese, Japanese and Arab annals. Appeals have been made to archaeologists for information on cave painting representations of the earlier Gum Supernova (Brandt, *et al.*, 1971). But supernova events are not nearly so impressive as the close approach of another planet with attendant interplanetary tendrils and lightning discharges connecting it to Earth. There are many unflooded caves at high altitudes, distant from the sea. If the Velikovskian catastrophes occurred, why are there no contemporary graphic records of them?

I therefore cannot find the legendary base of Velikovsky's hypothesis at all compelling. If, nevertheless, his notion of recent planetary collisions and global catastrophism were strongly supported by physical evidence, we might be tempted to give it some credence. If the physical evidence is not, however, very strong, the mythological evidence will surely not stand by itself.

LET ME GIVE a short summary of my understanding of the basic features of Velikovsky's principal hypothesis. I will relate it to the events described in the Book of *Exodus*, although the stories of many other cultures are said to be consistent with the events described in *Exodus*:

The planet Jupiter disgorged a large comet, which made a grazing collision with Earth around 1500 B.C. The various plagues and Pharaonic tribulations of the Book of *Exodus*

all derive directly or indirectly from this cometary encounter. Material which made the river Nile turn to blood drops from the comet. The vermin described in *Exodus* are produced by the comet – flies and perhaps scarabs drop out of the comet, while indigenous terrestrial frogs are induced by the heat of the comet to multiply. Earthquakes produced by the comet level Egyptian but not Hebrew dwellings. (The only thing that does not seem to drop from the comet is cholesterol to harden Pharaoh's heart.)

All this evidently falls from the coma of the comet because at the moment that Moses lifts his rod and stretches out his hand, the 'Red Sea' parts – due either to the gravitational tidal field of the comet or to some unspecified electrical or magnetic interaction between the comet and the 'Red Sea'. Then, when the Hebrews have successfully crossed, the comet has evidently passed sufficiently farther on for the parted waters to flow back and drown the host of Pharaoh. The Children of Israel during their subsequent forty years of wandering in the Wilderness of Sin are nourished by manna from heaven, which turns out to be hydrocarbons (or carbohydrates) from the tail of the comet.

Another reading of *Worlds in Collision* makes it appear that the plagues and the Red Sea events represent two different passages of the comet, separated by a month or two. Then after the death of Moses and the passing of the mantle of leadership to Joshua, the same comet comes screeching back for another grazing collision with the Earth. At the moment that Joshua says 'Sun, stand thou still upon Gibeon; and thou, Moon, in the valley of Ajalon', the Earth – perhaps because of tidal interaction again, or perhaps because of an unspecified magnetic induction in the crust of the earth – obligingly ceases its rotation, to permit Joshua victory in battle. The comet then makes a near-collision with Mars, so violent as to eject it out of its orbit so it makes two near-collisions with the Earth which destroy the army

f Sennacherib, the Assyrian king, as he was making life iserable for some subsequent generation of Israelites. The et result was to eject Mars into its present orbit and the omet into a circular orbit around the Sun, where it came the planet Venus – which previously, Velikovsky elieves, did not exist. The Earth meantime had somehow egun rotating again at almost exactly the same rate as efore these encounters. No subsequent aberrant planetary ehaviour has occurred since about the seventh century B.C., though it might have been common in the Second Millenium.

That this is a remarkable story no one – proponents and pponents alike – will disagree. Whether it is a likely story is, rtunately, amenable to scientific inquiry. Velikovsky's /pothesis makes certain predictions and deductions: that omets are ejected from planets; that comets are likely to ake near or grazing collisions with planets; that vermin ve in comets and in the atmospheres of Jupiter and Venus; at carbohydrates can be found in the same places; that nough carbohydrates fell in the Sinai peninsula for nourishent during forty years of wandering in the desert; that centric cometary or planetary orbits can be circularized in period of hundreds of years; that volcanic and tectonic ents on Earth and impact events on the Moon were contemporaneous with these catastrophes; and so on. I will scuss each of these ideas, as well as some others – for ample, that the surface of Venus is hot, which is clearly ss central to his hypothesis, but which has been widely dvertised as powerful *post hoc* support of it. I will also amine an occasional additional 'prediction' of Velikovsky for example, that the Martian polar caps are carbon or rbohydrates. My conclusion is that when Velikovsky is iginal he is very likely wrong, and that when he is right e idea has been pre-empted by earlier workers. There are so a large number of cases where he is neither right nor

original. The question of originality is important because o circumstances – for example, the high surface temperatur of Venus – which are said to have been predicted b Velikovsky at a time when everyone else was imaginin something very different. As we shall see, this is not quite th case.

In the following discussion, I will try to use simpl quantitative reasoning as much as possible. Quantitativ arguments are obviously a finer mesh with which to sif hypotheses than qualitative arguments. For example, if I sa that a large tidal wave engulfed the Earth, there is a wid range of catastrophes – from the flooding of littoral region to global inundation – which might be pointed to as suppor for my contention. But if I specify a tide 100 miles high I must be talking about the latter, and moreover, there migh be some critical evidence to counterindicate or support tide of such dimensions. However, so as to make th quantitative arguments tractable to the reader who is no very familiar with elementary physics, I have tried, par ticularly in the Appendices (following the References), t state all the essential steps in the quantitative developmen using the simplest arguments that preserve the essentia physics. Perhaps I need not mention that such quantitativ testing of hypotheses is entirely routine in the physical an biological sciences today. By rejecting the hypotheses that d not meet these standards of analysis, we are able to mov swiftly to hypotheses in better concordance with the facts

There is one further point about scientific method tha must be made. Not all scientific statements have equa weight. Newtonian dynamics and the laws of conservatio of energy and angular momentum are on extremely firm footing. Literally millions of separate experiments have bee performed on their validity – not just on Earth, but, usin the observational techniques of modern astrophysics, else where in the solar system, in other star systems, and eve

n other galaxies. On the other hand, questions on the nature f planetary surfaces, atmospheres and interiors are on nuch weaker footing, as the substantial debates on these natters by planetary scientists in recent years clearly idicates. A good example of this distinction is the ppearance in 1975 of Comet Kohoutek. This comet had rst been observed at a great distance from the Sun. On ne basis of the early observations, two predictions were nade. The first concerned the orbit of Comet Kohoutek – here it would be found at future times, when it would be bservable from the Earth before sunrise, when after sunset predictions based on Newtonian dynamics. These predic-ons were correct to within a gnat's eyelash. The second rediction concerned the brightness of the comet. This was ased on the guessed rate of vaporization of cometary ices o make a large cometary tail which brightly reflects sun-ght. This prediction was painfully in error, and the comet far from rivalling Venus in brightness – could not be seen t all by most naked-eye observers. But vaporization rates epend on the detailed chemistry and geometrical form of ne comet, which we know poorly at best. The same distinc-on between well-founded scientific arguments, and argu-ents based on a physics or chemistry that we do not fully nderstand, must be borne in mind in any analysis of *Worlds in Collision.* Arguments based on Newtonian ynamics or the conservation laws of physics must be ven very great weight. Arguments based on planetary sur-ce properties, for example, must have correspondingly sser weights. We will find that Velikovsky's arguments n into extremely grave difficulties on both these scores, ut the one set of difficulties is far more damaging than the ther.

PROBLEM I

THE EJECTION OF VENUS BY JUPITER

VELIKOVSKY's hypothesis begins with an event that has neve been observed by astronomers and that is inconsistent wit much that we know about planetary and cometary physics namely, the ejection of an object of planetary dimension from Jupiter, perhaps by its collision with some othe giant planet. Such a propagation of catastrophes, Veli kovsky promised, would be 'the theme of the sequel t *Worlds in Collision*' (page 373). Thirty years later, no seque of this description has appeared. From the fact that th aphelia (the greatest distances from the Sun) of the orbits o short-period comets have a statistical tendency to lie nea Jupiter, Laplace and other early astronomers hypothesize that Jupiter was the source of such comets. This is a unnecessary hypothesis because we now know that long period comets may be transferred to short-period traje tories by the perturbations of Jupiter; this view has not bee advocated for a century or two except by the Sovie astronomer V. S. Vsekhsviatsky, who seems to believe tha the moons of Jupiter eject comets out of giant volcanoes

To escape from Jupiter, such a comet must have kinetic energy of $\frac{1}{2}\ mv_e^2$, where m is the cometary mas and v_e is the escape velocity from Jupiter, which is abou 60 km/sec. Whatever the ejection event – volcanoes o collisions – some significant fraction, at least 10 percent, o this kinetic energy will go into heating the comet. Th minimum kinetic energy per unit mass ejected is then $\frac{1}{2}\ v_e$ $= 1.3 \times 10^{13}$ ergs per gramme, and the quantity that goe into heating is more than 2.5×10^{12} erg/gramme. The later heat of fusion of rock is about 4×10^9 ergs per gramme This is the heat that must be applied to convert hot soli rock near the melting point into a fluid lava. About 10^1 ergs/gm must be applied to raise rocks at low temperature

their melting point. Thus, any event that ejected a comet a planet from Jupiter would have brought it to a temperature of at least several thousands of degrees, and whether mposed of rocks, ices or organic compounds, would have mpletely melted it. It is even possible that it would have en entirely reduced to a rain of self-gravitating small dust rticles and atoms, which does not describe the planet nus particularly well. (Incidentally, this would appear to a good Velikovskian argument for the high temperature the surface of Venus, but, as described below, this is not s argument.)

Another problem is that the escape velocity from the Sun's avity at the distance of Jupiter is about 20 km/sec. The ction mechanism from Jupiter does not, of course, know is. Thus, if the comet leaves Jupiter at velocities less than out 60 km/sec, the comet will fall back to Jupiter; if greater an about $[(20)^2 + (60)^2]^{1/2} = 63$ km/sec, it will escape om the solar system. There is only a narrow and therefore likely range of velocities consistent with Velikovsky's pothesis.

A further problem is that the mass of Venus is very large more than 5×10^{27} grammes, or possibly larger originally, n Velikovsky's hypothesis, before it passed close to the Sun. he total kinetic energy required to propel Venus to Jovian cape velocity is then easily calculated to be on the order 10^{41} ergs, which is equivalent to all the energy radiated by e Sun to space in an entire year, and one hundred million nes more powerful than the largest solar flare ever served. We are asked to believe, without any further idence or discussion, an ejection event vastly more powerl than anything on the Sun, which is a far more energetic ject than Jupiter.

Any process that makes large objects makes more small jects. This is especially true in a situation dominated by llisions, as in Velikovsky's hypothesis. Here the com-

minution physics is well-known and a particle one-tenth a large as our biggest particle should be a hundred or thousand times more abundant. Indeed, Velikovsky ha stones falling from the skies in the wake of his hypo thesized planetary encounters, and imagines Venus an Mars trailing swarms of boulders; the Mars swarm, he says led to the destruction of the armies of Sennacherib. But this is true, if we had near-collisions with objects o planetary mass only thousands of years ago, we should hav been bombarded by objects of lunar mass hundreds of year ago; and bombardment by objects than can make crater a mile or so across should be happening every secon Tuesday. Yet there is no sign, on either the Earth or th Moon, of frequent recent collisions with such lower mas objects. Instead, the few objects that, as a steady-stat population, are moving in orbits that might collide with th Moon are just adequate, over geological time, to explain th number of craters observed on the lunar maria. The absenc of a great many small objects with orbits crossing the orb of the Earth is another fundamental objection to Vel kovsky's basic thesis.

PROBLEM II
REPEATED COLLISIONS AMONG THE EARTH, VENUS AND MARS

'THAT A COMET may strike our planet is not very probabl but the idea is not absurd' (page 40). This is precisel correct: it remains only to calculate the probabilities, whic Velikovsky has unfortunately left undone.

Fortunately, the relevant physics is extremely simple an can be performed to order of magnitude even without an consideration of gravitation. Objects on highly eccentr orbits, travelling from the vicinity of Jupiter to the vicinit of the Earth, are travelling at such high speeds that the

utual gravitational attraction to the object with which they re about to have a grazing collision plays a negligible role determining the trajectory. The calculation is performed Appendix 1, where we see that a single 'comet' with phelion (far point from the Sun) near the orbit of Jupiter nd perihelion (near point to the Sun) inside the orbit of enus should take at least 30 million years before it impacts e Earth. We also find in Appendix 1 that if the object a member of the currently observed family of objects on ich trajectories, the lifetime against collision exceeds the ge of the solar system.

But let us take the number 30 million years to give the aximum quantitative bias in favour of Velikovsky. Therere, the odds against a collision with the Earth in any given ar is 3×10^7 to 1; the odds against it in any given millenum are 30,000 to 1. But Velikovsky has (see, e.g., page 388) ot one but *five* or *six* near-collisions among Venus, Mars nd Earth – all of which seem to be statistically independent vents; that is, by his own account, there does not seem be a regular set of grazing collisions determined by the lative orbital periods of the three planets. (If there were, e would have to ask the probability that so remarkable a ay in the game of planetary billiards could arise within elikovsky's time constraints.) If the probabilities are dependent, then the joint probability of five such enounters in the same millennium is on the short side of $(3 \times 10^7/10^3)^{-5} = (3 \times 10^4)^{-5} = 4.1 \times 10^{-23}$, or almost 00 billion trillion to 1 odds. For six encounters in the same illennium the odds rise to $(3 \times 10^7/10^3)^{-6} = (3 \times 10^4)^{-6} = 7.3 \times 10^{-28}$, or about a trillion quadrillion to 1 odds. ctually, these are lower limits – both for the reason given ove and because close encounters with Jupiter are likely eject the impacting object out of the solar system altother, rather as Jupiter ejected the Pioneer 10 spacecraft. hese odds are a proper calibration of the validity of Veli-

kovsky's hypothesis, even if there were no other difficulties with it. Hypotheses with such small odds in their favour are usually said to be untenable. With the other problems mentioned both above and below, the probability that the full thesis of *Worlds in Collision* is correct becomes negligible.

PROBLEM III
THE EARTH'S ROTATION

MUCH OF THE indignation directed towards *Worlds in Collision* seems to have arisen from Velikovsky's interpretation of the story of Joshua and related legends as implying that the Earth's rotation was once braked to a halt. The image that the most outraged protesters seem to have had in mind is that in the movie version of H. G. Wells's story 'The Man Who Could Work Miracles': The Earth is miraculously stopped from rotating but, through an oversight, no provision is made for objects that are not nailed down, which then continue moving at their usual rate and therefore fly off the Earth at a speed of 1,000 miles per hour. But it is easy to see (Appendix 2) that a gradual deceleration of the Earth's rotation at 10^{-2}g or so could occur in a period of much less than a day. Then no one would fly off, and even stalactites and other delicate geomorphological forms could survive. Likewise, we see in Appendix 2 that the energy required to brake the Earth is not enough to melt it, although it would result in a noticeable increase in temperature: the oceans would have been raised to the boiling point of water, an event that seems to have been overlooked by Velikovsky's ancient sources.

These are, however, not the most serious objections to Velikovsky s exegesis of Joshua. Perhaps the most serious is at the other end: How does the Earth get started up again rotating at approximately the same rate of spin? The Earth

cannot do it by itself, because of the law of the conservation of angular momentum. Velikovsky does not even seem to be aware that this is a problem.

Nor is there any hint that braking the Earth to a 'halt' by cometary collision is any less likely than any other resulting spin. In fact, the chance of precisely cancelling the Earth's rotational angular momentum in a cometary encounter is tiny; and the probability that subsequent encounters, were they to occur, would start the Earth spinning again even approximately once every twenty-four hours is tiny squared.

Velikovsky is vague about the mechanism that is supposed to have braked the Earth's rotation. Perhaps it is tidal gravitational; perhaps it is magnetic. Both of these fields produce forces that decline very rapidly with distance. While gravity declines as the inverse square of the distance, tides decline as the inverse cube, and the tidal couple as the inverse sixth power. The magnetic dipole field declines as the inverse cube and any equivalent magnetic tides fall off even more steeply than gravitational tides. Therefore, the braking effect is almost entirely at the distance of closest approach. The characteristic time of this closest approach is clearly about R/v, where R is the radius of the Earth and v the relative velocity of the comet and the Earth. With v about 25 km/sec, the characteristic time works out to be under ten minutes. This is the full time available for the total effect of the comet on the rotation of the Earth. The corresponding acceleration is less than 0.1 g, so armies still do not fly off into space. But the characteristic time for acoustic propagation within the Earth – the minimum time for an exterior influence to make itself felt on the Earth as a whole – is eighty-five minutes. Thus, no cometary influence even in grazing collision could make the Sun stand still upon Gibeon.

Velikovsky's account of the history of the Earth's rotation is difficult to follow. On page 236 we have an

account of the motion of the Sun in the sky which by accident conforms to the appearance and apparent motion of the Sun as seen from the surface of Mercury, but not from the surface of the Earth; and on page 385 we seem to have an aperture to a wholesale retreat by Velikovsky – for here he suggests that what happened was not any change in the angular velocity of rotation of the earth, but rather a motion in the course of few hours of the angular momentum vector of the Earth from pointing approximately at right angles to the ecliptic plane as it does today to pointing in the direction of the Sun, like the planet Uranus. Quite apart from extremely grave problems in the physics of this suggestion, it is inconsistent with Velikovsky's own argument because earlier he has laid great weight on the fact that Eurasian and Near Eastern cultures reported prolonged day while North American cultures reported prolonged night. In this variant there would be no explanation of the report from Mexico. I think I see in this instance Velikovsky hedging on or forgetting his own strongest arguments from ancient writings. On page 386 we have a qualitative argument, not reproduced, claiming that the Earth could have been braked to a halt by a strong magnetic field. The field strength required is not mentioned but would clearly (cf. calculations in Appendix 4) have to be enormous. There is no sign in rock magnetization of terrestrial rocks ever having been subjected to such strong fields strengths and what is equally important, we have quite firm evidence from both Soviet and American spacecraft that the magnetic-field strength of Venus is negligibly small – far less than the Earth's own surface field of 0.5 gauss, which would itself have been inadequate for Velikovsky's purpose.

PROBLEM IV
TERRESTRIAL GEOLOGY AND LUNAR CRATERS

REASONABLY enough, Velikovsky believes that a near-collision of another planet with the Earth might have had dramatic consequences here – by gravitational tidal, electrical or magnetic influences (Velikovsky is not very clear on this). He believes (pages 96 and 97) 'that in the days of the Exodus, when the world was shaken and rocked ... *all* volcanoes vomited lava and *all* continents quaked.' (My emphasis.)

There seems little doubt that earthquakes would have accompanied such a near-collision. Apollo lunar seismometers have found that moonquakes are most common during lunar perigee, when the Earth is closest to the Moon, and there are at least some hints of earthquakes at the same time. But the claim that there were extensive lava flows and volcanism involving 'all volcanoes' is quite another story. Volcanic lavas are easily dated, and what Velikovsky should produce is a histogram of the number of lava flows on Earth as a function of time. Such a histogram will, I believe, show that not all volcanoes were active between 1500 and 700 B.C., and that there is nothing particularly remarkable about the volcanism of that epoch.

Velikovsky believes (page 115) that reversals of the geomagnetic field are produced by cometary close approaches. Yet the record from rock magnetization is clear – such reversals occur about every million years, and not in the last few thousand, and they recur more or less like clockwork. Is there a clock in Jupiter that aims comets at the Earth every million years? The conventional view is that the Earth experiences a polarity reversal of the self-sustaining dynamo that produces the Earth's magnetic field; it seems a much more likely explanation.

Velikovsky's contention that mountain building occurre a few thousand years ago is belied by all the geologica evidence, which puts those times at tens of millions of year ago and earlier. The idea that mammoths were deep-froze by a rapid movement of the Earth's geographical pole a fe thousands of years ago can be tested -- for example, b carbon-14 or amino-acid racemization dating. I should b very surprised if a very recent age results from suc tests.

Velikovsky believes that the Moon, not immune to th catastrophes which befell the Earth, had similar tectoni events occur on its surface a few thousand years ago, an that many of its craters were formed then (see Part 2 Chapter 9). There are some problems with this idea as wel samples returned from the Moon in the Apollo mission show no rocks melted more recently than a few hundre million years ago.

Furthermore, if lunar craters were to have formed abund antly 2,700 or 3,500 years ago, there must have been similar production at the same time of terrestrial crater larger than a kilometre across. Erosion on the Earth' surface is inadequate to remove any crater of this size i 2,700 years. There are not large numbers of terrestrial crater of this size and age; indeed, there is not a single one. On thes questions Velikovsky seems to have ignored the critica evidence. When the evidence is examined, it strongl counterindicates his hypothesis.

Velikovsky believes that the close passage of Venus o Mars to the Earth would have produced tides at least mil high (pages 70 and 71); in fact, if these planets were ever ten of thousands of kilometres away, as he seems to think, th tides, both of water and of the solid body of our plane would be hundreds of miles high. This is easily calculate from the height of the present water and body lunar tid since the tide height is proportional to the mass of the tid

roducing object and inversely proportional to the cube of
ıe distance. To the best of my knowledge, there is no
eological evidence for a global inundation of all parts of the
orld at any time between the sixth and fifteenth centuries
C. If such floods had occurred, even if they were brief,
ıey should have left some clear trace in the geological
cord. And what of the archaeological and palaeonto-
gical evidence? Where are the extensive faunal extinctions
f the correct date as a result of such floods? And where
the evidence of extensive melting in these centuries, near
here the tidal distortion is greatest?

PROBLEM V
CHEMISTRY AND BIOLOGY OF THE TERRESTRIAL PLANETS

ELIKOVSKY'S thesis has some peculiar biological and
ıemical consequences, which are compounded by some
raightforward confusions on simple matters. He seems not
) know (page 16) that oxygen is produced by green-plant
hotosynthesis on Earth. He makes no note of the fact that
ıpiter is composed primarily of hydrogen and helium,
hile the atmosphere of Venus, which he supposes to have
isen inside of Jupiter, is composed almost entirely of
ırbon dioxide. These matters are central to his ideas and
ose them very grave difficulties. Velikovsky holds that the
anna that fell from the skies in the Sinai peninsula was of
ometary origin and therefore that there are carbohydrates
ı both Jupiter and Venus. On the other hand, he quotes
opious sources for fire and naphtha falling from the skies,
hich he interprets as celestial petroleum ignited in the
arth's oxidizing atmosphere (pages 53 through 58).
ecause Velikovsky believes in the reality and identity of
oth sets of events, his book displays a sustained confusion
carbohydrates and hydrocarbons; and at some points he

seems to imagine that the Israelites were eating motor
rather than divine nutriment during their forty yea
wandering in the desert.

Reading the text is made still more difficult by
apparent conclusion (page 366) of Martian polar caps ma
of manna, which are described ambiguously as 'probal
in the nature of carbon'. Carbohydrates have a strong
micron infrared absorption feature, due to the stretchi
vibration of the carbon-hydrogen bond. No trace of t
feature was observed in infrared spectra of the Martian po
caps taken by the Mariner 6 and 7 spacecraft in 19
On the other hand, Mariner 6, 7 and 9 and Viking 1 and
have acquired abundant and persuasive evidence for froz
water and frozen carbon dioxide as the constituents of
polar caps.

Velikovsky's insistence on a celestial origin of petroleu
is difficult to understand. Some of his references,
example in Herodotus, provide perfectly natural descr
tions of the combustion of petroleum upon seepage to
surface in Mesopotamia and Iran. As Velikovsky hims
points out (pages 55–56), the fire-rain and naphtha stor
derive from precisely those regions of the Earth that ha
natural petroleum deposits. There is, therefore, a straig
forward terrestrial explanation of the stories in questio
The amount of downward seepage of petroleum in 2,7
years would not be very great. The difficulty in extracti
petroleum from the Earth, which is the cause of certa
practical problems today, would be greatly ameliorated
Velikovsky's hypothesis were true. It is also very diffic
to understand on his hypothesis how it is, if oil fell from
skies in 1500 B.C., that petroleum deposits are intimat
mixed with chemical and biological fossils of tens to hu
dreds of millions of years ago. But this circumstance
readily explicable if, as most geologists have conclude
petroleum arises from decaying vegetation, of the Carbo

erous and other early geological epochs, and not from omets.

Even stranger are Velikovsky's views on extraterrestrial e. He believes that much of the 'vermin', and particularly e flies referred to in *Exodus*, really fell from his comet – though he hedges on the extraterrestrial origin of frogs hile approvingly quoting from the Iranian text, the *undahis* (page 183), which seems to admit a rain of cosmic ogs. Let us consider flies only. Shall we expect houseflies *Drosophila melanogaster* in forthcoming explorations of e clouds of Venus and Jupiter? He is quite explicit: 'Venus and therefore also Jupiter – is populated by vermin' age 369). Will Velikovsky's hypothesis fall if no flies are ound?

The idea that, of all the organisms on Earth, flies alone are extraterrestrial origin is curiously reminiscent of Martin uther's exasperated conclusion that, while the rest of life as created by God, the fly must have been created by the evil because there is no conceivable practical use for it. ut flies are perfectly respectable insects, closely related anatomy, physiology and biochemistry to the other *secta*. The possibility that 4.6 billion years of independent olution on Jupiter – even if it were physically identical the Earth – would produce a creature indistinguishable om other terrestrial organisms is to misread seriously e evolutionary process. Flies have the same enzymes, the me nucleic acids and even the same genetic code (which anslates nucleic acid information into protein information) do all the other organisms on Earth. There are too many timate associations and identities between flies and other rrestrial organisms for them to have separate origins, as y serious investigation clearly shows.

In *Exodus*, Chapter 9, it is said that the cattle of Egypt l died, but of the cattle of the Children of Israel there ied not one'. In the same chapter we find a plague that

affects flax and barley but not wheat and rye. This fi
tuned host-parasite specificity is very strange for comet
vermin with no prior biological contact with Earth,
is readily explicable in terms of home-grown terrest
vermin.

Then there is the curious fact that flies metabo
molecular oxygen. There is no molecular oxygen on Jupi
nor can there be, because oxygen is thermodynamic
unstable in an excess of hydrogen. Are we to imagine t
the entire terminal electron transfer apparatus required
life to deal with molecular oxygen was adventitiou
evolved on Jupiter by Jovian organisms hoping someday
be transported to Earth? This would be yet a bigger mira
than Velikovsky's principal collisional thesis. Velikov
makes (page 187) a lame aside on the 'ability of ma
small insects . . . to live in an atmosphere devoid of oxyg
which misses the point. The question is how an organ
evolved on Jupiter could live in and metabolize an atm
phere rich in oxygen.

Next there is the problem of fly ablation. Small flies h
just the same mass and dimensions as small meteors, wh
are burned up at an altitude of about 100 kilometres wh
they enter the Earth's atmosphere on cometary trajector
Ablation accounts for the visibility of such meteors. N
only would cometary vermin be transformed rapidly i
fried flies on entrance into the Earth's atmosphere; th
would, as cometary meteors are today, be vaporized i
atoms and never 'swarm' over Egypt to the consternat
of the Pharaoh. Likewise, the temperatures attendant
ejection of the comet from Jupiter, referred to above, wo
fry Velikovsky's flies. Impossible to begin with, doubly fr
and atomized, cometary flies do not well survive criti
scrutiny.

Finally, there is a curious reference to intelligent ext
terrestrial life in *Worlds in Collision*. On page 364 V

ovsky argues that the near-collisions of Mars with Earth nd Venus 'make it highly improbable that any higher forms f life, if they previously existed there, survived on Mars'. ut when we examine the Mars as seen by Mariner 9 and iking 1 and 2, we find that something over one-third of the lanet has a modified cratered terrain somewhat reminiscent f the Moon and displays no sign of spectacular catas- ophes other than ancient impacts. The other half to two- hirds of the planet shows almost no sign whatever of such npacts, but instead displays dramatic evidence of major ctonic activity, lava flows and vulcanism about a billion ears ago. The small but detectable amount of impact ratering in this terrain shows that it was made much longer han several thousand years ago. There is no way to recon- le this picture with a view of a planet recently so devastated y impact catastrophism that all intelligent life would hereby have been eliminated. It is also by no means clear hy, if all life on Mars were to be exterminated in such ncounters, all life on Earth was not similarly exterminated.

PROBLEM VI
MANNA

ANNA, according to the etymology in *Exodus*, derives from ie Hebrew words *man-hu*, which means 'What is it?' Indeed, n excellent question! The idea of food falling from comets is ot absolutely straightforward. Optical spectroscopy of omet trails, even before *Worlds in Collision* was published 950), showed the presence of simple fragments of hydro- rbons, but no aldehydes – the building blocks of carbo- ydrates – were known then. They may nevertheless be resent in comets. However, from the passage of Comet ohoutek near the Earth, it is now known that comets ontain large quantities of simple nitriles – in particular, ydrogen cyanide and methyl cyanide. These are poisons,

and it is not immediately obvious that comets are good eat.

But let us put this objection aside, grant Velikovsky hypothesis, and calculate the consequences. How m manna is required to feed the hundreds of thousands Children of Israel for forty years (see *Exodus*, Chapter Verse 35)?

In *Exodus*, Chapter 16, Verse 20, we find that the ma left overnight was infested by worms in the morning – event possible with carbohydrates but extremely unlik with hydrocarbons. Moses may have been a better chem than Velikovsky. This event also shows that manna was storable. It fell every day for forty years according to Biblical account. We will assume that the quantity that every day was just sufficient to feed the Children of Isr although Velikovsky assures us (page 138) from Midras sources that the quantity that fell was adequate for thousand years rather than a mere forty. Let us assume t each Israelite ate on the order of a third of a kilogram manna per day, somewhat less than a subsistence d Then each will eat 100 kilograms per year and 4,000 k grams in forty years. Hundreds of thousands of Israeli the number explicitly mentioned in *Exodus*, will then c sume something over a million kilograms of manna dur the forty years' wandering in the desert. But we can imagine the debris from the cometary tail falling each da preferentially on the portion of the Wilderness of Sin

* Actually, *Exodus* states that manna fell each day except on the Sabb A double ration, uninfected by worms, fell instead on Friday. This se awkward for Velikovsky's hypothesis. How could the comet know? Ind this raises a general problem about Velikovsky's historical method. S quotations from his religious and historical sources are to be ta literally; others are to be dismissed as 'local embellishments'. But wh the standard by which this decision is made? Surely such a standard m involve a criterion independent of our predispositions towards Velikovs contentions.

vhich the Israelites happened to have wandered. This would e no less miraculous than the Biblical account taken at face alue. The area occupied by a few hundred thousand inerant tribesmen, wandering under a common leadership, , very roughly, several times 10^{-7} the area of the Earth. Therefore, during the forty years of wandering, all of the arth must have accumulated several times 10^{18} grammes of anna, or enough to cover the entire surface of the planet vith manna to a depth of about an inch. If this indeed appened, it would certainly be a memorable event, and ay even account for the gingerbread house in 'Hansel and retel'.

Now, there is no reason for the manna to have fallen only n Earth. In forty years the tail of the comet, if restricted o the inner solar system, would have traversed some 0^{10} km. Making only a modest allowance for the ratio f the volume of the Earth to the volume of the tail, we nd that the mass of manna distributed to the inner solar ystem by this event is larger than 10^{28} grammes. This is not nly more massive by many orders of magnitude than the ost massive comet known; it is already more massive than he planet Venus. But comets cannot be composed only of anna. (Indeed, no manna at all has been detected so far in omets.) Comets are known to be composed primarily of es, and a conservative estimate of the ratio of the mass of ne comet to the mass of the manna is much larger than 0^3. Therefore, the mass of the comet must be much larger han 10^{31} grammes. This is the mass of Jupiter. If we were o accept Velikovsky's Midrashic source above, we would educe that the comet had a mass comparable to that of the un. Interplanetary space in the inner solar system should ven today be filled with manna. I leave it to the reader to ake his own judgment on the validity of Velikovsky's ypothesis in the light of such calculations.

PROBLEM VII
THE CLOUDS OF VENUS

VELIKOVSKY'S prognostication that the clouds of Venus w
made of hydrocarbons or carbohydrates has many ti
been hailed as an example of a successful scientific p
diction. From Velikovsky's general thesis and the cal
lations just described above, it is clear that Venus should
saturated with manna, a carbohydrate. Velikovsky s
(page x) that 'the presence of hydrocarbon gases and dus
the cloud envelope of Venus would constitute a crucial t
for his ideas. It is also not clear whether 'dust' in
foregoing quotation refers to hydrocarbon dust or j
ordinary silicate dust. On the same page Velikovsky quo
himself as saying. 'On the basis of this research, I assu
that Venus must be rich in petroleum gases,' which see
to be an unambiguous reference to the components
natural gas, such as methane, ethane, ethylene and acetyle

At this point, a little history must enter our story. In
1930s and early 1940s, the only astronomer in the wo
concerning himself with planetary chemistry was the
Rupert Wildt, once of Göttingen, and later at Yale. It
Wildt who first identified methane in the atmospheres
Jupiter and Saturn, and it was he who first proposed
presence of higher hydrocarbon gases in the atmosphere
these planets. Thus, the idea that 'petroleum gases' mi
exist on Jupiter is not original with Velikovsky. Likew
it was Wildt who proposed that formaldehyde might b
constituent of the atmosphere of Venus, and that a car
hydrate polymer of formaldehyde might constitute
clouds. The idea of carbohydrates in the clouds of Ve
was not original with Velikovsky either, and it is diffi
to believe that one who so thoroughly researched the ast
nomical literature of the 1930s and 1940s was unaware
these papers by Wildt which relate so closely to Velikovsk

entral theme. Yet there is no mention whatever of the upiter phase of Wildt's work and only a footnote on ormaldehyde (page 368), without references, and without ny acknowledgment that Wildt had proposed carbo-ydrates on Venus. Wildt, unlike Velikovsky, understood ell the difference between hydrocarbons and carbo-ydrates; moreover, he performed unsuccessful spectro-copic searches in the near-ultraviolet for the proposed ormaldehyde monomer. Being unable to find the monomer, e abandoned the hypothesis in 1942. Velikovsky did not.

As I pointed out many years ago (Sagan, 1961), the apour pressure of simple hydrocarbons in the vicinity of the louds of Venus should make them detectable if they com-rise the clouds. They were not detectable then, and in the itervening years, despite a wide range of analytic tech-iques used, neither hydrocarbons nor carbohydrates have een found. These molecules have been searched for by high-esolution ground-based optical spectroscopy, including ourier transform techniques; by ultraviolet spectroscopy rom the Wisconsin Experimental Package of the Orbiting stronomical Observatory OAO-2; by ground-based infra-ed observations; and by direct entry probes of the Soviet Union and the United States. Not one of them has been ound. Typical abundance upper limits on the simplest ydrocarbons and on aldehydes, the building blocks of arbohydrates, are a few parts per million (Connes, *et al.*, 967; Owen and Sagan, 1972). [The corresponding upper mits for Mars are also a few parts per million (Owen and agan, 1972)]. All observations are consistent in showing hat the bulk of the Venus atmosphere is composed of arbon dioxide. Indeed, because the carbon is present in such n oxidized form, at best trace constituents of the simple educed hydrocarbons could be expected. Observations on he wings of the critical 3.5 micron region show not the ightest trace of the C-H absorption feature common to

both hydrocarbons and carbohydrates (Pollack, *et al.*, 197
All other absorption bands in the Venus spectrum, from
ultraviolet through the infrared, are now understood; no
of them is due to hydrocarbons or carbohydrates.
specific organic molecule has ever been suggested that
explain with precision the infrared spectrum of Venus a
is now known.

Moreover, the question of the composition of the Ve
clouds – a major enigma for centuries – was solved not lo
ago (Young and Young, 1973; Sill, 1972; Young, 19
Pollack, *et al.*, 1974). The clouds of Venus are compos
of an approximately 75 percent solution of sulphuric ac
This identification is consistent with the chemistry of
Venus atmosphere, in which hydrofluoric and hydrochlo
acid have also been found, with the real part of
refractive index, deduced from polarimetry, which is kno
to three significant figures (1.44); with the 11.2 micron a
3 micron (and, now, far-infrared) absorption features; a
with the discontinuity in the abundance of water vapo
above and below the clouds. These observed features
inconsistent with the hypothesis of hydrocarbon or carb
hydrate clouds.

With such organic clouds now so thoroughly discredit
why do we hear about space-vehicle research having c
roborated Velikovsky's thesis? This also requires a sto
On December 14, 1962, the first successful American int
planetary spacecraft, Mariner 2, flew by Venus. Built by
Jet Propulsion Laboratory, it carried, among other m
important instruments, an infrared radiometer for whic
happened to be one of four experimenters. This was at a ti
before even the first successful lunar Ranger spacecraft, a
NASA was comparatively inexperienced in releasing
scientific findings. A press conference was held in Washi
ton to announce the results, and Dr. L. D. Kaplan, one
the experimenters on our team, was delegated to descr

he results to the assembled reporters. It is clear that when his ime came, he described the results with somewhat the ollowing flavour (these are not his exact words): 'Our xperiment was a two-channel infrared radiometer, one hannel centred in the 10.4 micron CO_2 hot band; the ther in an 8.4 micron clear window in the gas phase of he Venus atmosphere. The objective was to measure bsolute brightness temperatures and differential trans- ission between the two channels. A limb-darkening law vas found in which the normalized intensity varied as mu to he power alpha, where mu is the arccosine of the angle etween the local planetary normal and the line of sight, nd –'

At some such point he was interrupted by impatient eporters, unused to the intricacies of science, who said omething like 'Don't tell us the dull stuff; give us the real oop! How thick are the clouds, how high are they, and what re they made of?' Kaplan replied, quite properly, that the nfrared radiometer experiment was not designed to test such uestions, nor did it. But then he said something like 'I'll ell you what I think.' He went on to describe his view that he greenhouse effect, in which an atmosphere is transparent o visible sunlight but opaque to infrared emission from the rface, needed to keep the surface of Venus hot, might not ork on Venus because the atmospheric constituents seemed o be transparent at a wavelength in the vicinity of 3.5 icrons. If some absorber at this wavelength existed in the enus atmosphere, the window could be plugged, the green- ouse effect retained, and the high surface temperature ccounted for. He proposed that hydrocarbons would be lendid greenhouse molecules.

Kaplan's cautions were not noted by the press, and the ext day headlines could be found in many American news- pers saying: 'Hydrocarbon Clouds Found on Venus by lariner 2.' Meanwhile, back at the Jet Propulsion Lab-

oratory publicists were in the process of writing a popul report on the mission, since called 'Mariner: Mission Venus'. One imagines them in the midst of writing, picki up the morning newspaper and saying, 'Hey! I didn't kn we found hydrocarbon clouds on Venus.' And, indeed, th publication lists hydrocarbon clouds as one of the princi discoveries of Mariner 2: 'At their base, the clouds are abo 200 degrees F and probably are comprised of condens hydrocarbon held in oily suspension.' (The report also op for greenhouse heating of the Venus surface, but Velikovs has chosen to believe only a part of what was printed.)

One now imagines the Administrator of NASA passi on the good tidings to the President in the annual report the Space Administration; the President handing it on another step in his annual report to Congress; and writers of elementary astronomy texts, always anxious include the very latest results, enshrining this 'finding' their pages. With so many apparently reliable, high-le and mutually consistent reports that Mariner 2 found hyd carbon clouds on Venus, it is no wonder that Velikovs and several fair-minded scientists, inexperienced in mysterious ways of NASA, might deduce that here is classic test of a scientific theory: an apparently biza prediction, made before the observation, and then unexp tedly confirmed by experiment.

The true situation is very different, as we have se Neither Mariner 2 nor any subsequent investigation of Venus atmosphere has found evidence for hydrocarbons carbohydrates, in gas, liquid or solid phase. It is now kno (Pollack, 1969) that carbon dioxide and water vapo adequately fill the 3.5 micron window. The Pioneer Ve mission in late 1978 found just the water vapour need along with the long-observed quantity of carbon dioxide, account for the high surface temperature through the gre house effect. It is ironic that the Mariner 2 'argument'

ydrocarbon clouds on Venus in fact derives from an tempt to rescue the greenhouse explanation of the high rface temperature, which Velikovsky does not support. is also ironic that Professor Kaplan was later a co-author a paper that established a very low abundance of methane, 'petroleum gas', in a spectroscopic examination of the enus atmosphere (Connes, *et al.*, 1967).

In summary, Velikovsky's idea that the clouds of Venus e composed of hydrocarbons or carbohydrates is neither iginal nor correct. The 'crucial test' fails.

PROBLEM VIII
THE TEMPERATURE OF VENUS

ANOTHER CURIOUS circumstance concerns the surface temrature of Venus. While the high temperature of Venus is ten quoted as a successful prediction and a support of Velivsky's hypothesis, the reasoning behind his conclusion id the consequences of his arguments do not seem to be idely known nor discussed.

Let us begin by considering Velikovsky's views on the mperature of Mars (pages 367–368). He believes that ars, being a relatively small planet, was more severely fected in its encounters with the more massive Venus and arth, and therefore that Mars should have a high temrature. He proposes that the mechanism may be 'a conrsion of motion into heat', which is a little vague, since at is precisely the motion of molecules or, much more ntastic, by 'interplanetary electrical discharges' which ould also initiate atomic fissions with ensuing radiotivity and emission of heat'.

In the same section, he baldly states, 'Mars emits more heat an it receives from the Sun', in apparent consistency with s collision hypothesis. This statement is, however, dead rong. The temperature of Mars has been measured

repeatedly by Soviet and American spacecraft and ground-based observers, and the temperatures of all part Mars are just what is calculated from the amount of sunli absorbed by the surface. What is more, this was well kno in the 1940s, before Velikovsky's book was published. A while he mentions four prominent scientists who w involved before 1950 in measuring the temperature of M he makes no reference to their work, and explicitly erroneously states that they concluded that Mars gave more radiation than it received from the Sun.

It is difficult to understand this set of errors, and most generous hypothesis I can offer is that Velikov confused the visible part of the electromagnetic spectr in which sunlight heats Mars, with the infrared part of spectrum, in which Mars largely radiates to space. But conclusion is clear. Mars, even more than Venus, by V kovsky's argument should be a 'hot planet'. Had M proved to be unexpectedly hot, perhaps we would h heard of this as a further confirmation of Velikovsk views. But when Mars turns out to have exactly the t perature everyone expected it to have, we do not hear of as a refutation of Velikovsky's views. There is a planet double standard at work.

When we now move on to Venus, we find rather sim arguments brought into play. I find it odd that Velikov does not attribute the temperature of Venus to its ejec from Jupiter (see Problem I, above), but he does Instead, we are told, because of its close encounter with Earth and Mars, Venus must have been heated, but (page 77) 'the head of the comet . . . had passed close to Sun and was in a state of candescence.' Then, when comet became the planet Venus, it must still have been 'v hot' and have 'given off heat' (page ix). Again pre-l astronomical observations are referred to (page 370), wh show that the dark side of Venus is approximately as ho

e bright side of Venus, to the level probed by middle-frared radiation. Here Velikovsky accurately quotes the tronomical investigators, and from their work deduces age 371) 'the night side of Venus radiates heat because enus is hot.' Of course!

What I think Velikovsky is trying to say here is that his nus, like his Mars, is giving off more heat than it receives om the Sun, and that the observed temperatures on both ght and day sides are due more to the 'candescence' of enus than to the radiation it now receives from the Sun. ut this is a serious error. The bolometric albedo (the action of sunlight reflected by an object at all wave-ngths) of Venus is about 0.73, entirely consistent with the served infrared temperature of the clouds of Venus of out 240 °K; that is to say, the clouds of Venus are precisely the temperature expected on the basis of the amount of nlight that is absorbed there.

Velikovsky proposed that both Venus and Mars give off ore heat than they receive from the sun. He is wrong for th planets. In 1949 Kuiper (see References) suggested that piter gives off more heat than it receives, and subsequent servations have proved him right. But of Kuiper's sug-stion *Worlds in Collision* breathes not a word.

Velikovsky proposed that Venus is hot because of its counters with Mars and the Earth, and its close passage to e Sun. Since Mars is not anomalously hot, the high rface temperature of Venus must be attributed primarily the passage of Venus near the Sun during its cometary carnation. But it is easy to calculate how much energy nus would have received during its close passage to the n and how long it would take for this energy to be radiated ay into space. This calculation is performed in Appendix where we find that all of this energy is lost in a period months to years after the close passage to the Sun, and at there is no chance of any of that heat being retained

at the present time in Velikovsky's chronology. Velikov does not mention how close to the Sun Venus is suppose have passed, but a very close passage compounds the alre extremely grave collision physics difficulties outlined Appendix 1. Incidentally, there is a slight hint in *World Collision* that Velikovsky believes that comets shine emitted rather than reflected light. If so, this may be source of some of his confusion regarding Venus.

Velikovsky nowhere states the temperature he belie Venus to be at in 1950. As mentioned above, on page 7 says vaguely that the comet that later became Venus wa a state of 'candescence', but in the preface to the 1 edition (page xi), he claims to have predicted 'an candescent state of Venus'. This is not at all the same th because of the rapid cooling after its supposed solar counter (Appendix 3). Moreover, Velikovsky himsel proposing that Venus is cooling through time, so w precisely Velikovsky meant by saying that Venus is 'ho to some degree obscure.

Velikovsky writes in the 1965 preface that his claim high surface temperature was 'in total disagreement w what was known in 1946.' This turns out to be not quite case. The dominant figure of Rupert Wildt again loo over the astronomical side of Velikovsky's hypothe Wildt, who, unlike Velikovsky, understood the nature the problem, predicted correctly that Venus and not M would be 'hot'. In a 1940 paper in the *Astrophysical Jour* Wildt argued that the surface of Venus was much ho than conventional astronomical opinion had held, beca of a carbon-dioxide greenhouse effect. Carbon dioxide recently been discovered spectroscopically in the atm phere of Venus, and Wildt correctly pointed out that observed large quantity of CO_2 would trap infrared rad tion given off by the surface of the planet until the surf temperature rose to a higher value, so that the incom

sible sunlight just balanced the outgoing infrared planetary emission. Wildt calculated that the temperature would almost 400 °K, or around the normal boiling point of ater (373 °K = 212 °F = 100 °C). There is no doubt that s was the most careful treatment of the surface temrature of Venus prior to the 1950s, and it is again odd at Velikovsky, who seems to have read all papers on nus and Mars published in the *Astrophysical Journal* in 1920s, 1930s and 1940s, somehow overlooked this hisrically significant work.

We now know from ground-based radio observations and om the remarkably successful direct entry and landing obes of the Soviet Union that the surface temperature of nus is within a few degrees of 750 °K (Marov, 1972). The rface atmospheric pressure is about ninety times that at surface of the Earth, and is comprised primarily of rbon dioxide. This large abundance of carbon dioxide, as the smaller quantities of water vapour which have been tected on Venus, are adequate to heat the surface to the served temperature via the greenhouse effect. The Venera lescent module, the first spacecraft to land on the illumited hemisphere of Venus, found it illuminated at the rface, and the Soviet experimenters concluded that the nount of sunlight reaching the surface and the atmospheric nstitution were together adequate to drive the required diative-convective greenhouse (Marov, *et al.*, 1973). These ults were confirmed by the Venera 9 and 10 missions, which tained clear photographs, in sunlight, of surface rocks. likovsky is thus certainly mistaken when he says (page ix) ght does not penetrate the cloud cover', and is probably staken when he says (page ix) the 'greenhouse effect could t explain so high a temperature.' These conclusions ceived important additional support late in 1978 from the S. Pioneer Venus mission.

A repeated claim by Velikovsky is that Venus is cooling

off with time. As we have seen, he attributes its high te
perature to solar heating during a close solar passage.
many publications Velikovsky compares published te
perature measurements of Venus, made at different tim
and tries to show the desired cooling. An unbiased pres
tation of the microwave brightness temperatures of Venu
the only nonspacecraft data that apply to the surface te
perature of the planet – are exhibited in Figure 1. T
error bars represent the uncertainties in the measurem
processes as estimated by the radio observers themselv
We see that there is not the faintest hint of a decline

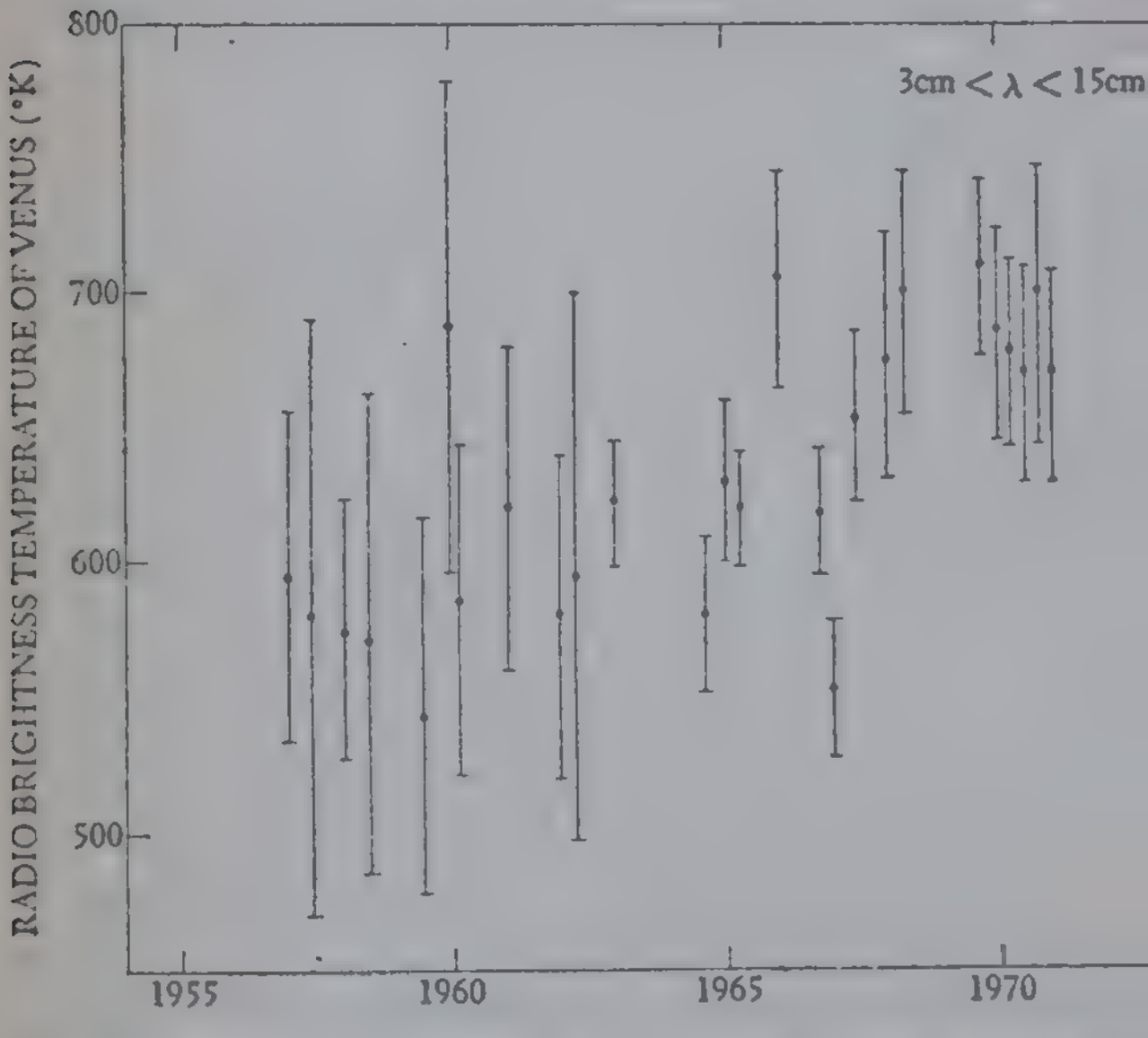

FIGURE 1. *Microwave brightness temperatures of Venus as a funct*
of time (after a compilation by D. Morrison). There is certainly
evidence of a declining surface temperature. The wavelength
observation is denoted by λ.

mperature with time (if anything, there is a suggestion of n increase with time, but the error bars are sufficiently rge that such a conclusion is also unsupported by the data). imilar results apply to measurements, in the infrared part f the spectrum, of cloud temperatures: they are lower in agnitude and do not decline with time. Moreover, the mplest considerations of the solution of the one-mensional equation of heat conduction show that in the elikovskian scenario essentially all the cooling by radiation space would have occurred long ago. Even if Velikovsky ere right about the source of the high Venus surface mperatures, his prediction of a secular temperature crease would be erroneous.

The high surface temperature of Venus is another of the -called proofs of the Velikovsky hypothesis. We find that) the temperature in question was never specified; (2) the echanism proposed for providing this temperature is ossly inadequate; (3) the surface of the planet does not ol off with time as advertised; (4) the idea of a high rface temperature on Venus was published in the minant astronomical journal of its time and with an sentially correct argument ten years before the publication *Worlds in Collision.*

PROBLEM IX

THE CRATERS AND MOUNTAINS OF VENUS

1973 AN IMPORTANT aspect of the surface of Venus, rified by many later observations, was discovered by r. Richard Goldstein and associates, using the Goldstone dar observatory of the Jet Propulsion Laboratory. They und, from radar that penetrates Venus' clouds and is flected off its surface, that the planet is mountainous in aces and cratered abundantly; perhaps, like parts of the oon, saturation-cratered – i.e., so packed with craters that

one crater overlaps the other. Because successive volca eruptions tend to use the same lava tube, saturation cra ing is more characteristic of impact than of volcanic cra ing mechanisms. This is not a conclusion predicted Velikovsky, but that is not my point. These craters, like craters in the lunar maria (plural for Latin *mare*, 'sea'), Mercury and in the cratered regions of Mars, are produ almost exclusively by the impact of interplanetary deb Large crater-forming objects are not dissipated as they e the Venus atmosphere, despite its high density. Now, colliding objects cannot have arrived at Venus in the past thousand years; otherwise, the Earth would be as plentif cratered. The most likely source of these collisions is Apollo objects (asteroids whose orbits cross the orbit of Earth) and small comets we have already discussed (App dix 1). But for them to produce as many craters as Ve possesses, the cratering process on Venus must have ta billions of years. Alternatively, the cratering may h occurred more rapidly in the very earliest history of solar system, when interplanetary debris was much m plentiful. But there is no way for it to have happe recently. On the other hand, if Venus was, several thous years ago, in the deep interior of Jupiter, there is no it could have accumulated such impacts there. The cl conclusion from the craters of Venus is, therefore, t Venus has for billions of years been an object exposed interplanetary collisions – in direct contradiction to fundamental premise of Velikovsky's hypothesis.

The Venus craters are significantly eroded. Some of rocks on the surface of the planet, as revealed by the Ven 9 and 10 photography, are quite young; others are seve eroded. I have described elsewhere possible mechanisms erosion on the Venus surface – including chemical weath ing and slow deformation at high temperatures (Sag 1976). However, these findings have no bearing whatever

e Velikovskian hypotheses: recent volcanic activity on nus need no more be attributed to a close passage to the n or to Venus being in some vague sense a 'young' planet an recent volcanic activity on Earth.

In 1967 Velikovsky wrote: 'Obviously, if the planet is lions of years old, it could not have preserved its original at; also, any radioactive process that can produce such at must be of a very rapid decay [*sic*], and this again uld not square with an age of the planet counted in lions of years.' Unfortunately, Velikovsky has failed to derstand two classic and basic geophysical results. ermal conduction is a much slower process than radiation convection, and, in the case of the Earth, primordial at makes a detectable contribution to the geothermal nperature gradient and to the heat flux from the Earth's erior. The same applies to Venus. Also, the radionuclides ponsible for radioactive heating of the Earth's crust are ng-lived isotopes of uranium, thorium and potassium – topes with half-lives comparable to the age of the planet. gain, the same applies to Venus.

If, as Velikovsky believes, Venus were completely molten ly a few thousand years ago – from planetary collisions any other cause – no more than a thin outer crust, at ost ~ 100 metres thick, could since have been produced by nductive cooling. But the radar observations reveal ormous linear mountain ranges, ringed basins, and a great valley, with dimensions of hundreds to thousands of ometres. It is very unlikely that such extensive tectonic or pact features could be stably supported over a liquid erior by such a thin and fragile crust.

PROBLEM X
THE CIRCULARIZATION OF THE ORBIT OF VENUS AND NONGRAVITATIONAL FORCES IN THE SOLAR SYSTEM

7689

THE IDEA that Venus could have been converted, in a f thousand years, from an object in a highly elongated eccentric orbit to its present orbit, which is – except f Neptune – the most nearly perfect circular orbit of all t planets, is at odds with what we know about the three-bo problem* in celestial mechanics. However, it must admitted that this is not a completely solved problem, a that, while the odds are large, they are not absolute overwhelming against Velikovsky's hypothesis on this sco Furthermore, when Velikovsky invokes electrical or ma netic forces, with no effort to calculate their magnitude describe in detail their effects, we are hard pressed to asse his ideas. However, simple arguments from the requir magnetic energy density to circularize a comet show th the field strengths implied are unreasonably high (Append 4) – they are counterindicated by studies of rock magnetiz tion.

We can also approach the problem empirically. Straigh forward Newtonian mechanics is able to predict wi remarkable accuracy the trajectories of spacecraft – so tha for example, the Viking orbiters were placed within 1 kilometres of their designated orbit; Venera 8 was place precisely on the sunlit side of the equatorial terminator Venus; and Voyager 1 was placed in exactly the correct ent corridor in the vicinity of Jupiter to be directed close Saturn. No mysterious electrical or magnetic influences we encountered. Newtonian mechanics is adequate to predic

* The prediction of the relative motions of three objects attracted to ea other gravitationally.

ith great precision, for example, the exact moment when
:e Galilean satellites of Jupiter will eclipse each other.
Comets, it is true, have somewhat less predictable orbits,
.it this is almost certainly because there is a boiling off of
ɔzen ices as these objects approach the Sun, and a small
cket effect. The cometary incarnation of Venus, if it
.isted, might also have had such icy vaporization, but there
no way in which the rocket effect would have preferentially
ought that comet into close passages with the Earth or
ars. Halley's comet, which has probably been observed
.r two thousand years, remains on a highly eccentric orbit
ıd has not been observed to show the slightest tendency
wards circularization; yet it is almost as old as Veli-
ɔvsky's 'comet'. It is extraordinarily unlikely that Veli-
ɔvsky's comet, had it ever existed, became the planet
enus.

SOME OTHER PROBLEMS

HE PRECEDING ten points are the major scientific flaws in
elikovsky's argument, as nearly as I can determine. I have
scussed earlier some of the difficulties with his approach
ancient writings. Let me here list a few of the miscel-
neous other problems I have encountered in reading
Worlds in Collision.

On page 280 the Martian moons Phobos and Deimos are
ıagined to have 'snatched some of Mars' atmosphere' and
thereby appear very bright. But it is immediately clear
at the escape velocity on these objects – perhaps 20 miles
:r hour – is so small as to make them incapable of retain-
g even temporarily any atmosphere; close-up Viking
ıotographs show no atmosphere and no frost patches; and
ey are among the darkest objects in the solar system.

Beginning on page 281, there is a comparison of the
blical Book of Joel and a set of Vedic hymns describing

'maruts'. Velikovsky believes that the 'maruts' were a h
of meteorites that preceded and followed Mars during
close approach to Earth, which he also believes is describ
in Joel. Velikovsky says (page 286): 'Joel did not copy fr
the Vedas nor the Vedas from Joel.' Yet, on page 2
Velikovsky finds it 'gratifying' to discover that the wo
'Mars' and 'marut' are cognates. But how, if the sto
in Joel and Vedas are independent, could the two wo
possibly be cognates?

On page 307 we find Isaiah making an accurate predicti
of the time of the return of Mars for another collision w
earth 'based on experience during previous perturbation
If so, Isaiah must have been able to solve the full three-bo
problem with electrical and magnetic forces thrown in, an
is a pity that this knowledge was not also passed down
us in the Old Testament.

On pages 366 and 367 we find an argument that Ven
Mars and Earth, in their interactions, must have exchang
atmospheres. If massive quantities of terrestrial molecul
oxygen (20 percent of our atmosphere) were transferred
Mars and Venus 3,500 years ago, they should be there still
massive amounts. The time scale for turnover of O_2 in t
Earth's atmosphere is 2,000 years, and that is by a biologic
process. In the absence of abundant biological respiratio
any O_2 on Mars and Venus 3,500 years ago should still
there. Yet we know quite definitely from spectroscopy th
O_2 is at best a tiny constituent of the already extremely th
Martian atmosphere (and is likewise scarce on Venus
Mariner 10 found evidence of oxygen in the atmosphere
Venus – but tiny quantities of atomic oxygen in the upp
atmosphere, not massive quantities of molecular oxygen
the lower atmosphere.

The dearth of O_2 on Venus also renders untenab
Velikovsky's belief in petroleum fires in the lower Ven
atmosphere – neither the fuel nor the oxidant is present

ppreciable amounts. These fires, Velikovsky believed, ould produce water, which would be photodissociated, elding O. Thus Velikovsky requires significant deep at- ospheric O_2 to account for upper atmospheric O. In fact, e O found is understood very well in terms of the photo- emical breakdown of the principal atmospheric con- ituent, CO_2, into CO and O. These distinctions seem to ve been lost on some of Velikovsky's supporters, who ized on the Mariner 10 findings as a vindication of *Worlds Collision.*

Since there is negligible oxygen and water vapour in the fartian atmosphere, Velikovsky argues, some other con- ituent of the Martian atmosphere must be derived from e Earth. The argument, unfortunately, is a *non sequitur.* elikovsky opts for argon and neon, despite the fact that ese are quite rare constituents of the Earth's atmosphere. he first published argument for argon and neon as major nstituents of the Martian atmosphere was made by arrison Brown in the 1940s. More than trace quantities of on are now excluded; about one percent argon was found / Viking. But even if large quantities of argon had been und on Mars, it would have provided no evidence for a elikovskian atmospheric exchange – because the most undant form of argon, ^{40}Ar, is produced by the radio- tive decay of potassium 40, which is expected in the crust Mars.

A much more serious problem for Velikovsky is the rela- e absence of N_2 (molecular nitrogen) from the Martian mosphere. The gas is relatively unreactive, does not freeze t at Martian temperatures and cannot rapidly escape m the Martian exosphere. It is the major constituent of e Earth's atmosphere but comprises only one percent of e Martian atmosphere. If such an exchange of gases curred, where is all the N_2 on Mars? These tests of the sumed gas exchange between Mars and the Earth, which

Velikovsky advocates, are poorly thought out in his w
ings; and the tests contradict his thesis.

WORLDS IN COLLISION is an attempt to validate Bi
cal and other folklore as history, if not theology. I ha
tried to approach the book with no prejudgments. I fi
the mythological concordances fascinating, and wo
further investigation, but they are probably explicable
diffusionist or other grounds. The scientific part of the te
despite all the claims of 'proofs', runs into at least
very grave difficulties.

Of the ten tests of Velikovsky's work described abo
there is not one case where his ideas are simultaneou
original and consistent with simple physical theory a
observation. Moreover, many of the objections – especia
Problems I, II, III and X – are objections of high weig
based on the motion and conservation laws of physics.
science, an acceptable argument must have a clearly set fo
chain of evidence. If a single link in the chain is broke
the argument fails. In the case of *Worlds in Collision*,
have the opposite case: virtually every link in the chain
broken. To rescue the hypothesis requires special pleadi
the vague invention of new physics, and selective inatte
tion to a plethora of conflicting evidence. According
Velikovsky's basic thesis seems to me clearly untenable
physical grounds.

Moreover, there is a dangerous potential problem wi
the mythological material. The supposed events are reco
structed from legends and folktales. But these global cata
trophes are not present in the historical records or folklo
of many cultures. Such strange omissions are accounted fo
when they are noted at all, by 'collective amnesia'. Ve
kovsky wants it both ways. Where concordances exist, he
prepared to draw the most sweeping conclusions from the
Where concordances do not exist, the difficulty is dismiss

y invoking 'collective amnesia'. With so lax a standard of idence, anything can be 'proved'.

I should also point out that a much more plausible planation exists for most of the events in *Exodus* that elikovsky accepts, an explanation that is much more in cord with physics. The Exodus is dated in *I Kings* as curring 480 years before the initiation of the construction the Temple of Solomon. With other supporting calculaons, the date for the Biblical Exodus is then computed to about 1447 B.C. (Covey, 1975). Other Biblical scholars sagree, but this date is consistent with Velikovsky's ronology, and is astonishingly close to the dates obtained a variety of scientific methods for the final and lossal volcanic explosion of the island of Thera (or ntorin) which may have destroyed the Minoan civilization Crete and had profound consequences for Egypt, less than ree hundred miles to the south. The best available radiorbon date for the event, obtained from a tree buried in lcanic ash on Thera, is 1456 B.C. with an error in the ethod of at least plus or minus forty-three years. The nount of volcanic dust produced is more than adequate to count for three days of darkness in daytime, and accomnying events can explain earthquakes, famine, vermin and range of familiar Velikovskian catastrophes. It also may ve produced an immense Mediterranean *tsunami*, or tidal ve, which Angelos Galanopoulos (1964) – who is responle for much of the recent geological and archaeological erest in Thera – believes can account for the parting of the d Sea as well.* In a certain sense, the Galanopoulos planation of the events in *Exodus* is even more provocative an the Velikovsky explanation, because Galanopoulos has esented moderately convincing evidence that Thera

* An informative and entertaining discussion of the Thera case, and the ole question of the connection of myth with geological events, can be nd in the book by Vitaliano (1973); see also de Camp (1975).

corresponds in almost all essential details to the legend
civilization of Atlantis. If he is right, it is the destructi
of Atlantis rather than the apparition of a comet th
permitted the Israelites to leave Egypt.

There are many strange inconsistencies in *Worlds*
Collision, but on the next-to-last page of the book, a breat
taking departure from the fundamental thesis is casua
introduced. We read of a hoary and erroneous analo
between the structures of solar systems and of aton
Suddenly we are presented with the hypothesis that t
supposed errant motions of the planets, rather than bei
caused by collisions, are instead the result of changes in t
quantum energy levels of planets attendant to the abso
tion of a photon – or perhaps several. Solar systems a
held together by gravitational forces; atoms by electri
forces. While both forces depend on the inverse square
distance, they have totally different characters and magn
tudes: as one of many differences, there are positive a
negative electrical charges, but only one sign of gravitation
mass. We understand both solar systems and atoms w
enough to see that Velikovsky's proposed 'quantum jump
of planets are based on a misunderstanding of both theori
and evidence.

To the best of my knowledge, in *Worlds in Collision* the
is not a single correct astronomical prediction made wi
sufficient precision for it to be more than a vague luck
guess – and there are, as I have tried to point out, a ho
of demonstrably false claims. The existence of strong rad
emission from Jupiter is sometimes pointed to as the mo
striking example of a correct prediction by Velikovsky, b
all objects give off radio waves if they are at temperatur
above absolute zero. The essential characteristics of t
Jovian radio emission – that it is nonthermal, polarize
intermittent radiation, connected with the vast belts
charged particles which surround Jupiter, trapped by

ong magnetic field – are nowhere predicted by Veli-
vsky. Further, his 'prediction' is clearly not linked in its
entials to the fundamental Velikovskian theses.

Merely guessing something right does not necessarily
nonstrate prior knowledge or a correct theory. For
ımple, in an early science-fiction work dated 1949, Max
rlich imagined a near-collision of the Earth with another
smic object, which filled the sky and terrorized the
ıabitants of the Earth. Most frightening was the fact that
this passing planet was a natural feature which looked
y much like a huge eye. This is one of many fictional and
ious antecedents to Velikovsky's idea that such collisions
ppen frequently. But that is not my point. In a discussion
how it is that the side of the Moon facing the Earth
s large smooth maria while the averted face of the
ɔon is almost free of them, John Wood of the Smithsonian
trophysical Observatory proposed that the side of the
ɔon now turned towards the Earth was once at the edge,
limb, of the Moon, on the leading hemisphere of the
ɔon's motion about the Earth. In this position it swept
, billions of years ago, a ring of debris which surrounded
Earth and which may have been involved in the forma-
n of the Earth-Moon system. By Euler's laws, the Moon
st then have altered its rotation axis to correspond to its
v principal moment of inertia, so that its leading hemi-
ıere then faced the Earth. The remarkable conclusion is
.t there would have been a time, according to Wood, when
at is now the eastern limb of the Moon would have been
ing the Earth. But the eastern limb of the Moon has an
ɔrmous collision feature, billions of years old, called Mare
ientale, which looks very much like a giant eye. No one
s suggested that Ehrlich was relying upon a racial memory
an event three billion years old when he wrote *The Big*
?. It is merely a coincidence. When enough fiction is
.tten and enough scientific hypotheses are proposed,

sooner or later there will be accidental concordances.

With these enormous liabilities, how is it that *W* *in Collision* has been so popular? Here I can only g For one thing, it is an attempted validation of religion old Biblical stories are literally true, Velikovsky tells only we interpret them in the right way. The Jewish pe for example, saved from Egyptian Pharaohs, Assyrian and innumerable other disasters by obliging com interventions, had every right, he seems to be sayin believe themselves chosen. Velikovsky attempts to r not only religion but also astrology: the outcomes of the fates of whole peoples, are determined by the positio the planets. In some sense, his work holds out a pro of the cosmic connectedness of mankind – a sentiment which I sympathize, but in a somewhat different co (*The Cosmic Connection*) – and the reassurance that an peoples and other cultures were not so very dumb, afte

The outrage that seems to have seized many othe placid scientists upon colliding with *Worlds in Collisio* produced a chain of consequences. Some people are properly put off by the occasional pomposity of scien or are concerned by what they apprehend as the dan of science and technology, or perhaps merely have diffi understanding science. They may take some comfo seeing scientists get their deserts.

In the entire Velikovsky affair, the only aspect worse the shoddy, ignorant and doctrinaire approach of kovsky and many of his supporters was the disgra attempt by some who called themselves scientists to supp his writings. For this, the entire scientific enterprise suffered. Velikovsky makes no serious claim of object or falsifiability. There is at least nothing hypocritical i rigid rejection of the immense body of data that co dicts his arguments. But scientists are supposed to k

tter, to realize that ideas will be judged on their merits if we rmit free inquiry and vigorous debate.

To the extent that scientists have not given Velikovsky the asoned response his work calls for, we have ourselves been sponsible for the propagation of Velikovskian confusion. it scientists cannot deal with all areas of borderline ence. The thinking, calculations and preparation of this apter, for example, took badly needed time away from y own research. But it was certainly not boring, and at e very least I had a brush with many an enjoyable legend.

The attempt to rescue old-time religion, in an age which ems desperately to be seeking some religious roots, some smic significance for mankind, may or may not be credit-le. I think there is much good and much evil in the old-ne religions. But I do not understand the need for lf-measures. If we are forced to choose between them – d we *decidedly* are not – is the evidence not better for the od of Moses, Jesus and Muhammed than for the comet of elikovsky?

CHAPTER 8

NORMAN BLOOM, MESSENGER OF GOD

* * *

[The French encyclopaedist] Diderot paid a visit to the Russian Court at the invitation of the Empress. He conversed very freely, and gave the younger members of the Court circle a good deal of lively atheism. The Empress was much amused, but some of her councillors suggested that it might be desirable to check these expositions of doctrine. The Empress did not like to put a direct muzzle on her guest's tongue, so the following plot was contrived. Diderot was informed that a learned mathematician was in possession of an algebraical demonstration of the existence of God, and would give it him before all the Court, if he desired to hear it. Diderot gladly consented: though the name of the mathematician is not given, it was Euler. He advanced towards Diderot, and said gravely, and in a tone of perfect conviction: *Monsieur*, $(a + b^n)/n = x$, *donc Dieu existe; répondez!* [Sir, $(a + b^n)/n = x$. Therefore God exists: reply!] Diderot, to whom algebra was Hebrew, was embarrassed and disconcerted; while peals of laughter arose on all sides. He asked permission to return to France at once, which was granted.

AUGUSTUS DE MORGAN,
A Budget of Paradoxes (1872)

THROUGHOUT human history there have been attempt contrive rational arguments to convince sceptics of existence of a God or gods. But most theologians h held that the ultimate reality of divine beings is a ma for faith alone and is inaccessible to rational endeav St. Anselm argued that since we can imagine a perfect be he must exist – because he would not be perfect with the added perfection of existence. This so-called ontolog argument was more or less promptly attacked on

unds: (1) *Can* we imagine a completely perfect being? *Is* it obvious that perfection is augmented by existence? the modern ear such pious arguments seem to be about rds and definitions rather than about external reality.

More familiar is the argument from design, an approach t penetrates deeply into issues of fundamental scientific icern. This argument was admirably summarized by vid Hume: 'Look round the world: contemplate the ole and every part of it; you will find it to be nothing one great machine, subdivided into an infinite number esser machines.... All these various machines, even their st minute parts, are adjusted to each other with an uracy which ravishes into admiration all men who have r contemplated them. The curious adapting of means to s, throughout all nature, resembles exactly, though it ch exceeds, the production of human contrivance; of nan design, thought, wisdom and intelligence. Since refore the effects resemble each other, we are led to infer, all the rules of analogy, that the causes also resemble; l that the Author of Nature is somewhat similar to the id of man; though possessed of much larger faculties portioned to the grandure of the work which he has cuted.'

Hume then goes on to subject this argument, as did manuel Kant after him, to a devastating and compelling ack, notwithstanding which the argument from design tinued to be immensely popular – as, for example, in works of William Paley through the early nineteenth tury. A typical passage by Paley goes: 'There cannot be esign without a designer; contrivance without a contrivor; er without choice; arrangement without anything capable rranging; subserviency and relation to a purpose, without t which could intend a purpose; means suitable to an , and executing their office and accomplishing that end, hout the end ever having been contemplated, or the

means accommodated to it. Arrangement, dispositio
parts, subserviency of means to an end, relation of in
ments to a use, imply the presence of intelligence
mind.'

It was not until the development of modern science
most particularly the brilliant formulation of the theo
evolution by natural selection, put forth by Charles Da
and Alfred Russel Wallace in 1859, that these appare
plausible arguments were fatally undermined.

There can, of course, be no disproof of the existenc
God – particularly a sufficiently subtle God. But it
kindness neither to science nor religion to leave unc
lenged inadequate arguments for the existence of
Moreover, debates on such questions are good fun, ar
the very least, hone the mind for useful work. Not m
of this sort of disputation is in evidence today, per
because new arguments for the existence of God which
be understood at all are exceedingly rare. One recent
modern version of the argument from design was ki
sent to me by its author, perhaps to secure constru
criticism.

NORMAN BLOOM is a contemporary American who incid
ally believes himself to be the Second Coming of J
Christ. Bloom observes in Scripture and everyday
numerical coincidences which anyone else would con
meaningless. But there are so many such coincidences
Bloom believes, they can be due only to an unseen i
ligence, and the fact that no one else seems to be ab
find or appreciate such coincidences convinces Bloom
he has been chosen to reveal God's presence. Bloom has
a fixture at some scientific meetings where he harangue
hurrying, preoccupied crowds moving from sessio
session. Typical Bloom rhetoric is 'And though you r
me, and scorn me, and deny me, YET ALL WILL

OUGHT ONLY BY ME. My will will be, because I have ned you out of the nothingness. You are the Creation My Hands. And I will complete My Creation and nplete My Purpose that I have Purposed from of old. M THAT I AM. I AM THE LORD THY GOD IN UTH.' He is nothing if not modest, and the capitaliza- conventions are entirely his.

loom has issued a fascinating pamphlet, which states: e complete faculty of Princeton University (including officers and its deans and the chairmen of the depart- its listed here) has agreed that it cannot refute, nor w in basic error the proof brought to it, in the book, *New World* dated Sept. 1974. This faculty acknowledges f June 1, 1975 that it accepts as a proven truth THE EFUTABLE PROOF THAT AN ETERNAL MIND D HAND HAS SHAPED AND CONTROLLED THE TORY OF THE WORLD THROUGH THOU- NDS OF YEARS.' A closer reading shows that despite om's distributing his proofs to over a thousand faculty nbers of Princeton University, and despite his offer of 1,000 prize for the first individual to refute his proof, e was no response whatever. After six months he con- led that since Princeton did not answer, Princeton eved. Considering the ways of university faculty nbers, an alternative explanation has occurred to me. In case, I do not think that the absence of a reply stitutes irrefutable support for Bloom's arguments.

Princeton has apparently not been alone in treating om inhospitably: 'Yes, times almost without number, I e been chased by police for bringing you the gift of my ing ... Is it not so that professors at a university are posed to have the maturity and judgment and wisdom e able to read a writing and determine for themselves value of its contents? Is it that they require THOUGHT NTROL POLICE to tell them what they should or

should not read or think about? But, even at the astro
department of Harvard University, I have been chas
police for the crime of distributing that New
Lecture, an irrefutable proof that the earth-moo
system is shaped by a controlling mind and hand. Ye
THREATENED WITH IMPRISONMENT, IF I D
BESMIRCH THE HARVARD CAMPUS WITH
PRESENCE ONCE MORE.... AND THIS IS
UNIVERSITY THAT HAS UPON ITS SHIELD
WORD VERITAS: VERITAS: VERITAS: – Truth, T
Truth. Ah, what hypocrites and mockers you are!'

The supposed proofs are many and diverse, all invo
numerical coincidences which Bloom believes could n
due to chance. Both in style and content, the argu
are reminiscent of Talmudic textual commentary and c
istic lore of the Jewish Middle Ages: for example, the an
size of the Moon or the Sun as seen from the Ea
half a degree. This is just 1/720 of the circle (360) c
sky. But $720 = 6! = 6 \times 5 \times 4 \times 3 \times 2 \times 1$. Therefore,
exists. It is an improvement on Euler's proof to Dic
but the approach is familiar and infiltrates the entire hi
of religion. In 1658 Gaspar Schott, a Jesuit priest
nounced in his *Magia Universalis Naturae et Artis* tha
number of degrees of grace of the Virgin Mary is
$= 2^{2^3} \simeq 1.2 \times 10^{77}$ (which, by the by, is very ro
the number of elementary particles in the universe).

Another Bloomian argument is described as 'irrefu
proof that the God of Scripture is he who has shaped
controlled the history of the world through thousan
years.' The argument is this: according to Chapters 5 a
of Genesis, Abraham was born 1,948 years after Adam
time when Abraham's father, Terah, was seventy year
But the Second Temple was destroyed by the Roma
A.D. 70, and the State of Israel was created in A.D.
Q.E.D. It is hard to escape the impression that there

flaw in the argument somewhere. 'Irrefutable' is, after a fairly strong word. But the argument is a refreshing ersion from St. Anselm.

loom's central argument, however, and the one that h of the rest is based upon, is the claimed astronomical cidence that 235 new moons is, with spectacular racy, just as long as nineteen years. Whence: 'Look, kind, I say to you all, in essence you are living in a k. The clock keeps perfect time, to an accuracy of second/day! ... How could such a clock in the heavens e to be without there being some being, who with ception and understanding, who, with a plan and with the er, could form that clock?'

fair question. To pursue it we must realize that there several different kinds of years and several different ls of months in use in astronomy. The sidereal year e period that the Earth takes to go once around the with respect to the distant stars. It equals 365.2564 days. e days we will use, as Norman Bloom does, are what onomers call 'mean solar days'.) Then there is the tropi- year. It is the period for the Earth to make one circuit ut the Sun with respect to the seasons, and equals .242199 days. The tropical year is different from the real year because of the precession of the equinoxes, slow toplike movement of the Earth produced by the itational forces of the Sun and the Moon on its oblate e. Finally, there is the so-called anomalistic year of 2596 days. It is the interval between two successive est approaches of the Earth to the Sun, and is different n the sidereal year because of the slow movement of Earth's elliptical orbit in its own plane, produced by itational tugs by the nearby planets.

ikewise, there are several different kinds of months. The d 'month', of course, comes from 'moon'. The sidereal nth is the time for the Moon to go once around the

earth with respect to the distant stars and equals 27
days. The synodic month, also called a lunation, is th
from new moon to new moon or full moon to full mo
is 29.530588 days. The synodic month is different fro
sidereal month because, in the course of one si
revolution of the Moon about the Earth, the Earth-
system has together revolved a little bit (about
thirteenth) of the way around the Sun. Therefore the
by which the Sun illuminates the Moon has changed
our terrestrial vantage point. Now, the plane of the M
orbit around the Earth intersects the plane of the E
orbit around the Sun at two places – opposite to
other – called the nodes of the Moon's orbit. A nodi
draconic month is the time for the Moon to move
one node back around again to the same node and
27.21220 days. These nodes move, completing one app
circuit, in 18.6 years because of gravitational tugs,
by the Sun. Finally, there is the anomalistic mon
27.55455 days, which is the time for the Moon to com
one circuit of the Earth with respect to the nearest
in its orbit. A little table on these various definitions
year and the month is shown below.

KINDS OF YEARS AND MONTHS,
EARTH-MOON SYSTEM

Years	
Sidereal year	365.2564 mean solar da
Tropical year	365.242199 days
Anomalistic year	365.2596 days
Months	
Sidereal month	27.32166 days
Synodic month	29.530588 days
Nodical or draconic month	27.21220 days
Anomalistic month	27.55455 days

v, Bloom's main proof of the existence of God depends
n choosing one of the sorts of years, multiplying it by 19
then dividing by one of the sorts of months. Since the
real, tropical and anomalistic years are so close together
ngth, we get sensibly the same answer whichever one
hoose. But the same is not true for the months. There are
different kinds of months, and each gives a different
ver. If we ask how many *synodic* months there are in a
real year, we find the answer to be 235.00621, as
rtised; and it is the closeness of this result to a whole
ber that is the fundamental coincidence of Bloom's
is. Bloom, of course, believes it to be no coincidence.
ut if we were to ask instead how many *sidereal* months
e are in nineteen sidereal years we would find the answer
e 254.00622; for nodical months, 255.02795; and for
nalistic months, 251.85937. It is certainly true that the
odic month is the one most strikingly apparent to a
ed-eye observer, but I nevertheless have the impression
one could construct equally elaborate theological
ulations on 252, 254, or 255 as on 235.

We must now ask where the number 19 comes from in
argument. Its only justification is David's lovely
teenth Psalm, which begins: 'The heavens declare the
y of God, and the firmament sheweth his handiwork.
unto day uttereth speech, and night unto night
veth knowledge.' This seems quite an appropriate
tation from which to find a hint of an astronomical
of for the existence of God. But the argument assumes
t it intends to prove. The argument is also not unique.
sider, for example, the Eleventh Psalm, also written by
id. In it we find the following words, which may equally
bear on this question: 'The Lord is in his holy temple,
Lord's throne is in heaven: his eyes behold, his eyelids
the children of men', which is followed in the following
m with 'the children of men . . . speak vanity'. Now, if we

ask how many synodic months there are in eleven
years (or 4017.8204 mean solar days), we find the an
be 136.05623. Thus, just as there seems to be a con
between nineteen years and 235 new moons, there is
nection between eleven years and 136 new moons. Mo
the famous British astronomer Sir Arthur Stanley Edd
believed that all of physics could be derived fr
number 136. (I once suggested to Bloom that w
foregoing information and just a little intellectual fort
should be possible as well to reconstruct all of E
history.)

One numerical coincidence of this sort, which *is* s
significance, was well known to the Babylonians, c
poraries of the ancient Hebrews. It is called the Sa
is the period between two successive similar cy
eclipses. In a solar eclipse the Moon, which appear
the Earth just as large (1/2) as the Sun, must p
front of it. For a lunar eclipse, the Earth's shadow i
must intercept the Moon. For either kind of ecl
occur, the Moon must, first of all, be either new or f
that the Earth, the Moon and the Sun are in a s
line. Therefore the synodic month is obviously invo
the periodicity of eclipses. But for an eclipse to occ
Moon must also be near one of the nodes of its
Therefore the nodical month is involved. It turns o
233 synodic months is equal to 241.9989 (or very c
242) nodical months. This is the equivalent of a litt
eighteen years and ten or eleven days (depending
number of intervening leap days), and comprises the
Coincidence?

Similar numerical coincidences are in fact co
throughout the solar system. The ratio of spin per
orbital period on Mercury is 3 to 2. Venus manages
the same face to the Earth at its closest approach o
of its revolutions around the Sun. A particle in t

een the two principal rings of Saturn, called the Cassini sion, would orbit Saturn in a period just half that of as, its second satellite. Likewise, in the asteroid belt are empty regions, known as the Kirkwood Gaps, h correspond to nonexistent asteroids with periods half of Jupiter, one-third, two-fifths, three-fifths, and so

one of these numerical coincidences proves the existence od – or if it does, the argument is subtle, because these ts are due to resonances. For example, an asteroid that 's into one of the Kirkwood Gaps experiences a periodic itational pumping by Jupiter. Every two times around un for the asteroid, Jupiter makes exactly one circuit. e it is, tugging away at the same point in the asteroid's every revolution. Soon the asteroid is persuaded to te the gap. Such incommensurable ratios of whole bers are a general consequence of gravitational reson- in the solar system. It is a kind of perturbational ral selection. Given enough time – and time is what olar system has a great deal of – such resonances will inevitably.

nat the general result of planetary perturbations is stable nances and not catastrophic collisions was first shown n Newtonian gravitational theory by Pierre Simon, quis de Laplace, who described the solar system as 'a t pendulum of eternity, which beats ages as a pendulum s seconds'. Now, the elegance and simplicity of New- n gravitation might be used as an argument for the ence of God. We could imagine universes with other itational laws and much more chaotic planetary interac- s. But in many of those universes we would not have ved – precisely because of the chaos. Such gravitational nances do not prove the existence of God, but if he exist, they show, in the words of Einstein, that, while nay be subtle, he is not malicious.

BLOOM CONTINUES his work. He has, for example, strated the preordination of the United States of A by the prominence of the number 13 in major leag ball scores on July 4, 1976. He has accepted my ch and made an interesting attempt to derive some of h history from numerology – at least the assassina Archduke Ferdinand at Sarajevo, the event that preci World War I. One of his arguments involves the c which Sir Arthur Stanley Eddington presented a talk mystical number 136 at Cornell University, where h And he has even performed some numerical manipu using my birth date to demonstrate that I also am the cosmic plan. These and similar cases convince m Bloom can prove anything.

Norman Bloom is, in fact, a kind of genius. If e independent phenomena are studied and corre sought, some will of course be found. If we know o coincidences and not the enormous effort and ma successful trials that preceded their discovery, we believe that an important finding has been made. Ac it is only what statisticians call 'the fallacy of the en tion of favourable circumstances'. But to find as coincidences as Norman Bloom has requires great sk dedication. It is in a way a forlorn and perhap hopeless objective – to demonstrate the existence o by numerical coincidences to an uninterested, to say m of a mathematically unenlightened public. It is e imagine the contributions Bloom's talents might hav in another field. But there is something a little glor find, in his fierce dedication and very considerable metic intuition. It is a combination of talents which might also say, God-given.

CHAPTER 9

SCIENCE FICTION – A PERSONAL VIEW

* * *

The poet's eye, in a fine frenzy rolling,
Doth glance from heaven to earth, from earth to heaven;
And as imagination bodies forth
The forms of things unknown, the poet's pen
Turns them to shapes, and given to airy nothing
A local habitation and a name.

WILLIAM SHAKESPEARE,
A Midsummer Night's Dream, Act V, Scene 1

THE TIME I was ten I had decided – in almost total orance of the difficulty of the problem – that the verse was full up. There were too many places for this be the only inhabited planet. And judging from the iety of life on Earth (trees looked pretty different from st of my friends), I figured life elsewhere would look y strange. I tried hard to imagine what that life would like, but despite my best efforts I always produced a d of terrestrial chimaera, a blend of existing plants and mals.

About this time a friend introduced me to the Mars els of Edgar Rice Burroughs. I had not thought much ut Mars before, but here, presented before me in the ventures of John Carter, was an inhabited extraterrestrial rld breathtakingly fleshed out: ancient sea bottoms, great al-pumping stations and a variety of beings, some of m exotic. There were, for example, the eight-legged beasts burden, the thoats.

These novels were exhilarating to read. At first. Then

slowly doubts began to gnaw. The plot surprise
first John Carter novel I read hinged on him fo
that the year is longer on Mars than on Earth. But it
to me that if you go to another planet, one of t
things you check into is the length of the day and th
(Incidentally, I can recall no mention by Carter
remarkable fact that the Martian day is almost as l
the terrestrial day. It was as if he *expected* the fa
features of his home planet somewhere else.) Then ther
incidental remarks made which were at first stunning
sober reflection disappointing. For example, Burr
casually comments that on Mars there are two more p
colours than on Earth. I spent many long minutes w
eyes tightly closed, fiercely concentrating on a new p
colour. But it would always be a murky brown or a
How could there be another primary colour on Mars,
less two? What *was* a primary colour? Was it sometl
do with physics or something to do with physiol
decided that Burroughs might not have known what
talking about, but he certainly made his readers think
in those many chapters where there was not much to
about, there were satisfyingly malignant enemies and
ing swordsmanship – more than enough to mainta
interest of a citybound ten-year-old in a Brooklyn su

A year later, by sheerest accident, I stumbled ac
magazine called *Astounding Science Fiction* in the
bourhood candy store. A glance at the cover and a
riffle through the interior showed me it was what
been looking for. With some effort I managed to
together the purchase price, opened it at random, sat
on a bench not twenty feet from the candy store an
my first modern science-fiction short story, 'Pete Can
by Raymond F. Jones, a gentle time-travel story of
nuclear-war holocaust. I knew about the atom bon
remember an excited friend explaining to me that

e of atoms – but this was the first I had seen about social implications of the development of nuclear pons. It got you thinking. The little device, though, that the garage mechanic put on automobiles so passers-by ht make brief cautionary trips into the wasteland of the re – what was that little device? How was it made? How d you get into the future and then come back? If mond F. Jones knew, he wasn't telling.

found I was hooked. Each month I eagerly awaited rrival of *Astounding*. I read Jules Verne and H. G. Wells, from cover to cover the first two science-fiction nologies that I was able to find, made scorecards, lar to those I was fond of making for baseball, on quality of the stories I read. Many of the stories ranked in asking interesting questions but low in answering n.

here is still a part of me that is ten years old. But by and e I'm older. My critical faculties and perhaps even my ary tastes have improved. In rereading L. Ron Hubd's *The End Is Not Yet*, which I had first read at fourteen, I was so amazed at how much worse it was n I had remembered that I seriously considered the sibility that there were two novels of the same name by the same author but of vastly differing quality. I can longer manage credulous acceptance as well as I used In Larry Nivens' *Neutron Star* the plot hinges on the nishing tidal forces exerted by a strong gravitational . But we are asked to believe that hundreds or thousands ears from now, at a time of casual interstellar spacet, such tidal forces have been forgotten. We are asked believe that the first probe of a neutron star is done n manned rather than by an unmanned spacecraft. We asked too much. In a novel of ideas, the ideas have to k.

had the same kind of disquieting feelings many years

earlier on reading Verne's description that weight
on a lunar voyage occurred only at the point in spac
the Earth's and the Moon's gravitational pulls ca
and in Wells's invention of the antigravity mineral c
Why should a vein of cavorite still be on Earth? Shou
have flung itself into space long ago? In Douglas
bull's technically proficient science-fiction film *Silen*
ning, the trees in vast closed spaceborne ecological s
are dying. After weeks of painstaking study and ag
searches through botany texts, the solution is found:
it turns out, need sunlight. Trumbull's characters are
build interplanetary cities but have forgotten the i
square law. I was willing to overlook the portrayal
rings of Saturn as pastel-coloured gases, but not thi

I have the same trouble with *Star Trek*, which I
has a wide following and which some thoughtful frien
me I should view allegorically and not literally. But
astronauts from Earth set down on some far-distant
and find the human beings there in the midst of a c
between two nuclear superpowers – which call them
the Yangs and the Coms, or their phonetic equival
the suspension of disbelief crumbles. In a global terr
society centuries in the future, the ship's officers ar
barrassingly Anglo-American. Only two of twelve or
interstellar vessels are given non-English names, *Kong*
Potemkin. (*Potemkin* and not *Aurora*?) And the idea
successful cross between a 'Vulcan' and a terrestrial s
ignores what we know of molecular biology. (As I
remarked elsewhere, such a cross is about as likely
successful mating of a man and a petunia.) Accordi
Harlan Ellison, even such sedate biological novelties a
Spock's pointy ears and permanently querulous eyeb
were considered by network executives far too daring
enormous differences between Vulcans and humans
only confuse the audience, they thought, and a mov

le to have all physiologically distinguishing Vulcanian
ures effaced. I have similar problems with films in which
iliar creatures, slightly changed – spiders thirty feet tall
:e menacing the cities of the Earth: since insects and
:hnids breathe by diffusion, such marauders would
ıyxiate before they could savage their first city.

believe that the same thirst for wonder is inside me
was there when I was ten. But I have learned since
ı a little bit about how the world is really put together.
d that science fiction has led me to science. I find science
:e subtle, more intricate and more awesome than much
cience fiction. Think of some of the scientific findings of
last few decades: that Mars is covered with ancient
rivers; that apes can learn languages of many
dreds of words, understand abstract concepts and con-
ct new grammatical usages; that there are particles that
ı effortlessly through the entire Earth so that we see as
ıy of them coming up through our feet as down from
sky; that in the constellation Cygnus there is a double
, one of whose components has such a high gravitational
:leration that light cannot escape from it: it may be
:ing with radiation on the inside but it is invisible from
outside. In the face of all this, many of the standard
ıs of science fiction seem to me to pale by comparison.
: the relative absence of these things and the distortions
cientific thinking often encountered in science fiction as
ible wasted opportunities. Real science is as amenable
:xciting and engrossing fiction as fake science, and I
ık it is important to exploit every opportunity to convey
ntific ideas in a civilization which is both based upon
nce and does almost nothing to ensure that science is
lerstood.

But the best of science fiction remains very good indeed.
:re are stories so tautly constructed, so rich in accom-
dating details of an unfamiliar society that they sweep me

along before I even have a chance to be critical
stories include Robert Heinlein's *The Door into Su*
Alfred Bester's *The Stars My Destination* and
Demolished Man, Jack Finney's *Time and Again*,
Herbert's *Dune* and Walter M. Miller's *A Canti*
Leibowitz. You can ruminate over the ideas in these
Heinlein's asides on the feasibility and social uti
household robots wear exceedingly well over the year
insights into terrestrial ecology provided by hypot
extraterrestrial ecologies as in *Dune* perform, I thi
important social service. *He Who Shrank*, by Harry
presents an entrancing cosmological speculation wh
being seriously revived today, the idea of an infinite
of universes – in which each of our elementary pa
is a universe one level down, and in which we a
elementary particle in the next universe up.

A rare few science-fiction novels combine extraord
well a deep human sensitivity with a standard science-
theme. I am thinking, for example, of Algis Budrys'
Moon, and of many of the works of Ray Bradbur
Theodore Sturgeon – for example, the latter's *To He*
the Easel, a stunning portrayal of schizophrenia as per
from the inside, as well as a provocative introduct
Ariosto's *Orlando Furioso*.

There was once a subtle science-fiction story b
astronomer Robert S. Richardson on the contin
creation origin of cosmic rays. Isaac Asimov's story *Br*
There a Man provided a poignant insight into the emo
stress and sense of isolation of some of the best theo
scientists. Arthur C. Clarke's *The Nine Billion Na*
God introduced many Western readers to an intr
speculation in Oriental religions.

One of the great benefits of science fiction is that
convey bits and pieces, hints and phrases, of know
unknown or inaccessible to the reader. Heinlein's *A*

a Crooked House was for many readers probably the introduction they had ever encountered to four-nsional geometry that held any promise of being rehensible. One science-fiction work actually presents iathematics of Einstein's last attempt at a unified field y; another presents an important equation in popula-genetics. Asimov's robots were 'positronic', because ositron had recently been discovered. Asimov never ded any explanation of how positrons run robots, but aders had now heard of positrons. Jack Williamson's omagnetic robots were run off ruthenium, rhodium and dium, the next Group VIII metals after iron, nickel and t in the periodic table. An analogue with ferromag-n was suggested. I suppose that there are science-fiction s today that are quark-ish or charm-ing and will de some brief verbal entrée into the excitement of mporary elementary particle physics. L. Sprague de o's *Lest Darkness Fall* is an excellent introduction to e at the time of the Gothic invasion, and Asimov's *dation* series, although this is not explained in the s, offers a very useful summary of some of the dynamics far-flung imperial Roman Empire. Time-travel stories xample, the three remarkable efforts by Heinlein, *All Zombies*, *By His Bootstraps* and *The Door into Summer* ce the reader into contemplations of the nature of lity and the arrow of time. They are books you er over as the water is running out of the bathtub or u walk through the woods in an early winter snow-

other great value of modern science fiction is some of t forms it elicits. A fuzzy imagining in the mind's eye of the surface of another planet might look like is one , but examining a meticulous painting of the same by Chesley Bonestell in his prime is quite another. sense of astronomical wonder is splendidly conveyed

by the best of such contemporary artists – Don Da
Lomberg, Rick Sternbach, Robert McCall. And in t
of Diane Ackerman can be glimpsed the prospe
mature astronomical poetry, fully conversant with s
science-fiction themes.

Science-fiction ideas are widespread today in so
different guises. We have science-fiction writers such
Asimov and Arthur C. Clarke providing cogent and
summaries in nonfictional form of many aspects of
and society. Some contemporary scientists are int
to a vaster public by science fiction. For example
thoughtful novel *The Listeners*, by James Gunn, we
following comment made fifty years from now ab
colleague, the astronomer Frank Drake: 'Drake! W
he know?' A great deal, it turns out. We also find
science fiction disguised as fact in a vast prolifera
pseudoscientific writings, belief systems and organi

One science-fiction writer, L. Ron Hubbard, has f
a successful cult called Scientology – invented, acco
one account, overnight on a bet that he could do as
Freud, invent a religion and make money from it.
science-fiction ideas are now institutionalized in unid
flying objects and ancient-astronaut belief sys
although I have difficulty not concluding that
Weinbaum (in *The Valley of Dreams*) did it better,
as earlier, than Erich von Däniken. R. De Witt M
Within the Pyramid manages to anticipate bo
Däniken and Velikovsky, and to provide a more c
hypothesis on the supposed extraterrestrial or
pyramids than can be found in all the writings on
astronauts and pyramidology. In *Wine of the Drea*
John D. MacDonald (a science-fiction author nov
mogrified into one of the most interesting conten
writers of detective fiction), we find the sentence 'a
are traces, in Earth mythology . . . of great ships and

crossed the sky.' The story *Farewell to the Master*, by y Bates, was converted into a motion picture, *The the Earth Stood Still* (which abandoned the essential element, that on the extraterrestrial spacecraft it was the t and not the human who was in command). The movie, its depiction of a flying saucer buzzing Washington, is ght by some sober investigators to have played a role e 1952 Washington, D.C., UFO 'flap' which followed ly the release of the motion picture. Many popular ls today of the espionage variety, in the shallowness eir characterizations and the gimmickry of their plots, irtually indistinguishable from pulp science fiction of '30s and '40s.

NTERWEAVING of science and science fiction sometimes uces curious results. It is not always clear whether life tes art or vice versa. For example, Kurt Vonnegut, Jr., written a superb epistemological novel, *The Sirens of n*, in which a not altogether inclement environment is ulated on Saturn's largest moon. When in the last few s some planetary scientists, myself among them, pre- d evidence that Titan has a dense atmosphere and aps higher temperatures than expected, many people mented to me on the prescience of Kurt Vonnegut. Vonnegut was a physics major at Cornell University naturally knowledgeable about the latest findings in nomy. (Many of the best science-fiction writers have ce or engineering backgrounds; for example, Poul erson, Isaac Asimov, Arthur C. Clarke, Hal Clement Robert Heinlein.) In 1944, an atmosphere of methane discovered on Titan, the first satellite in the solar system vn to have an atmosphere. In this, as in many similar s, art imitates life.

he trouble has been that our understanding of the other ets has been changing faster than the science-fiction

representations of them. A clement twilight zone synchronously rotating Mercury, a swamp-and- Venus and a canal-infested Mars, while all classic s fiction devices, are all based upon earlier misapprehe by planetary astronomers. The erroneous ideas were fully transcribed into science-fiction stories, which then read by many of the youngsters who were to b the next generation of planetary astronomers – t simultaneously capturing the interest of the youngste making it more difficult to correct the misapprehensi the oldsters. But as our knowledge of the plane changed, the environments in the corresponding s fiction stories have also changed. It is quite rare to science-fiction story written today that involves algae on the surface of Venus. (Incidentally, the UFO-c mythologizers are slower to change, and we can st accounts of flying saucers from a Venus popula beautiful human beings in long white robes inhabiting of Cytherean Garden of Eden. The 900° Fahrenheit te tures of Venus give us one way of checking such st Likewise, the idea of a 'space warp' is a hoary s fiction standby but it did not arise in science fiction. I from Einstein's General Theory of Relativity.

The connection between science-fiction depicti Mars and the actual exploration of Mars is so clos subsequent to the Mariner 9 mission to Mars, we we to name a few Martian craters after deceased science- personalities. (See Chapter 11.) Thus there are on craters named after H. G. Wells, Edgar Rice Burr Stanley Weinbaum and John W. Campbell, Jr. These have been officially approved by the International nomical Union. No doubt other science-fiction perso will be added soon after they die.

THE GREAT INTEREST of youngsters in science fic

cted in films, television programmes, comic books and a
and for science-fiction courses in high schools and
:ges. My experience is that such courses can be fine
'ational experiences or disasters, depending on how they
lone. Courses in which the readings are selected by the
ents provide no opportunity for the students to read
t they have not already read. Courses in which there
: attempt to extend the science-fiction plot line to en-
pass the appropriate science miss a great educational
ortunity. But properly planned science-fiction courses,
hich science or politics is an integral component, would
ı to me to have a long and useful life in school
icula.

he greatest human significance of science fiction may
s experiments on the future, as explorations of alterna-
destinies, as attempts to minimize future shock. This
art of the reason that science fiction has so wide an
:al among young people: it is *they* who will live in the
re. It is my firm view that no society on Earth today is
adapted to the Earth of one or two hundred years from
(if we are wise enough or lucky enough to survive that
). We desperately need an exploration of alternative
res, both experimental and conceptual. The novels and
es of Eric Frank Russell were very much to this point.
hem, we were able to see conceivable alternative
ıomic systems or the great efficiency of a unified passive
tance to an occupying power. In modern science fiction,
ul suggestions can also be found for making a revolution
computerized technological society, as in Heinlein's *The*
on Is a Harsh Mistress.

ıch ideas, when encountered young, can influence adult
ıviour. Many scientists deeply involved in the explora-
of the solar system (myself among them) were first
ed in that direction by science fiction. And the fact that
e of that science fiction was not of the highest quality

is irrelevant. Ten-year-olds do not read the sci literature.

I do not know if time travel into the past is possibl causality problems it would imply make me very sce But there are those who are thinking about it. Wh called closed time-like lines – routes in space-time perm unrestricted time travel – appear in some solutions general relativistic field equations. A recent claim, p mistaken, is that closed time-like lines appear in the v of a large, rapidly rotating cylinder. I wonder to extent general-relativists working on such problems been influenced by science fiction. Likewise, science- encounters with alternative cultural features may p important role in actualizing fundamental social cha

In all the history of the world there has never befor a time in which so many significant changes have occ Accommodation to change, the thoughtful pursuit of native futures are keys to the survival of civilizatio perhaps of the human species. Ours is the first gene that has grown up with science-fiction ideas. I know young people who will of course be interested but way astounded if we receive a message from an terrestrial civilization. They have already accommoda that future. I think it is no exaggeration to say that survive, science fiction will have made a vital contri to the continuation and evolution of our civilization

PART III

OUR NEIGHBOURHOOD IN SPACE

CHAPTER 10

THE SUN'S FAMILY

* * *

Like a shower of stars the worlds whirl, borne along by the winds of heaven, and are carried down through immensity; suns, earths, satellites, comets, shooting stars, humanities, cradles, graves, atoms of the infinite, seconds of eternity, perpetually transform beings and things.

CAMILLE FLAMMARION,
Popular Astronomy, translated by J. E. Gore
(New York, D. Appleton & Company, 1894)

IMAGINE THE EARTH scrutinized by some very careful and extremely patient extraterrestrial observer: 4.6 billion years the planet is observed to complete its condensation out interstellar gas and dust, the final planetesimals falling in make the Earth produce enormous impact craters; the et heats internally from the gravitational potential gy of accretion and from radioactive decay, differentiat- the liquid iron core from the silicate mantle and crust; rogen-rich gases and condensible water are released from nterior of the planet to the surface; a rather humdrum nic organic chemistry yields complex molecules, which to extremely simple self-replicating molecular systems – first terrestrial organisms; as the supply of impacting planetary boulders dwindles, running water, mountain ding and other geological processes wipe out the scars ndant to the Earth's origin; a vast planetary convection ne is established which carries mantle material up at the n floors and subducts it down at the continental gins, the collision of the moving plates producing the t folded mountain chains and the general configuration

of land and ocean, glaciated and tropical terrain continuously. Meanwhile, natural selection extrac from a wide range of alternatives those varieties c replicating molecular systems best suited to the ch environments; plants evolve that use visible light to down water into hydrogen and oxygen, and the hyd escapes to space, changing the chemical composition atmosphere from reducing to oxidizing; organisms c complexity and middling intelligence eventually aris

Yet in all the 4.6 billion years our hypothetical ob is struck by the isolation of the Earth. It receives su and cosmic rays – both important for biology – occasional impact of interplanetary debris. But noth all those eons of time leaves the planet. And then the suddenly begins to fire tiny dispersules throughout the solar system, first in orbit around the Earth, then planet's blasted and lifeless natural satellite, the Moo capsules – small, but larger than the rest – set dow the Moon, and from each, two tiny bipeds can be disc briefly exploring their surroundings and then hotfoo back to the Earth, having extended tentatively a toe in cosmic ocean. Eleven little spacecraft enter the atmos of Venus, a searing hellhole of a world, and six of survive some tens of minutes on the surface before fried. Eight spacecraft are sent to Mars. Three succes orbit the planet for years; another flies past Ven encounter Mercury, on a trajectory obviously c intentionally to pass by the innermost planet many Four others successfully traverse the asteroid belt, fly to Jupiter and are there ejected by the gravity of the planet into interstellar space. It is clear that som interesting is happening lately on the planet Earth.

If the 4.6 billion years of the Earth history were pressed into a single year, this flurry of space explo would have occupied the last tenth of a second, a

lamental changes in attitude and knowledge responsible
this remarkable transformation would fill only the last
seconds. The seventeenth century saw the first wide-
ad application of simple lenses and mirrors for astro-
ical purposes. With the first astronomical telescope
leo was astounded and delighted to see Venus as a
nt, and the mountains and the craters of the Moon.
nnes Kepler thought that the craters were constructions
ıtelligent beings inhabiting that world. But the seven-
th-century Dutch physicist Christianus Huygens dis-
ed. He suggested that the effort involved in constructing
lunar craters would be unreasonably great, and also
ıght that he could see alternative explanations for these
ılar depressions.

uygens exemplified the synthesis of advancing tech-
ogy, experimental skills, a reasonable, hard-nosed and
tical mind, and an openness to new ideas. He was the
to suggest that we are looking at atmosphere and clouds
Venus; the first to understand something of the true
ıre of the rings of Saturn (which had seemed to Galileo
wo 'ears' enveloping the planet); the first to draw a
ure of a recognizable marking on the Martian surface
tis Major); and the second, after Robert Hooke, to draw
Great Red Spot of Jupiter. These last two observations
still of scientific importance because they establish the
nanence at least for three centuries of these features.
gens was of course not a thoroughly modern astron-
r. He could not entirely escape the fashions of belief of
time. For example, he presented a curious argument
n which we could deduce the presence of hemp on
ter: Galileo had observed that Jupiter has four moons.
gens asked a question few modern planetary astron-
rs would ask: *Why* does Jupiter have four moons? An
ght into this question, he thought, could be garnered by
ng the same question of the Earth's single moon, whose

function, apart from giving a little light at night and
the tides, was to provide a navigational aid to mari
Jupiter has four moons, there must be many mari
that planet. But mariners imply boats; boats imply sa
imply ropes; and, I suppose, ropes imply hemp. I
how many of our present highly prized scientific arg
will seem equally suspect from the vantage point o
centuries.

A useful index of our knowledge about a planet
number of bits of information necessary to character
understanding of its surface. We can think of this
number of black and white dots in the equivalen
newspaper wirephoto which, held at arm's length,
summarize all existing imagery. Back in Huygens
about ten bits of information, all obtained by brief gl
through telescopes, would have covered our knowle
the surface of Mars. By the time of the close appro
Mars to Earth in the year 1877, this number had ri
perhaps a few thousand, if we exclude a large amo
erroneous information – for example, drawings
'canals', which we now know to be entirely illusory
further visual observations and the development of g
based astronomical photography, the amount of inf
tion grew slowly until a dramatic upturn in the
occurred, corresponding to the advent of space-
exploration of the planet.

The twenty photographs obtained in 1965 by the M
4 fly-by comprised five million bits of information, r
comparable to all previous photographic knowledge
the planet. The coverage was still only a tiny fraction
planet. The dual fly-by mission, Mariner 6 and 7 in
increased this number by a factor of 100, and the M
9 orbiter in 1971 and 1972 increased it by another
of 100. The Mariner 9 photographic results from
correspond roughly to 10,000 times the total previous

ıic knowledge of Mars obtained over the history of
kind. Comparable improvements apply to the infrared
ultraviolet spectroscopic data obtained by Mariner 9,
ɔared with the best previous ground-based data.
ɔing hand in hand with the improvement in the quantity
ır information is the spectacular improvement in its
ty. Prior to Mariner 4, the smallest feature reliably
·ted on the surface of Mars was several hundred
ıetres across. After Mariner 9, several percent of the
:t had been viewed at an effective resolution of 100
:s, an improvement in resolution of a factor of 1,000
: last ten years, and a factor of 10,000 since Huygens'
Still further improvements were provided by Viking.
only because of this improvement in resolution that
ɔday know of vast volcanoes, polar laminae, sinuous
·taried channels, great rift valleys, dune fields, crater-
:iated dust streaks, and many other features, instructive
·nysterious, of the Martian environment.
·th resolution and coverage are required to understand
wly explored planet. For example, even with their
·ior resolution, by an unlucky coincidence the Mariner
nd 7 spacecraft observed the old, cratered and relatively
:eresting part of Mars and gave no hint of the young
geologically active third of the planet revealed by
:ner 9.

ɔN EARTH is wholly undetectable by orbital photography
about 100-metre resolution is achieved, at which point
:ban and agricultural geometrizing of our technological
zation becomes strikingly evident. Had there been a
zation on Mars of comparable extent and level of
lopment, it would not have been detected photo-
:ically until the Mariner 9 and Viking missions. There
reason to expect such civilizations on the nearby planets,
ıe comparison strikingly illustrates that we are just begin-

ning an adequate reconnaissance of neighbouring world

THERE IS NO question that astonishments and delights aw
us as both resolution and coverage are dramatically i
proved in photography, and comparable improvements a
secured in spectroscopic and other methods.

The largest professional organization of planetary sci
tists in the world is the Division for Planetary Sciences
the American Astronomical Society. The vigour of t
burgeoning science is apparent in the meetings of the socie
In the 1975 annual meeting, for example, there w
announcements of the discovery of water vapour in
atmosphere of Jupiter, ethane on Saturn, possible hyd
carbons on the asteroid Vesta, an atmospheric press
approaching that of the Earth on the Saturnian moon Tit
decametre-wavelength radio bursts from Saturn, the ra
detection of the Jovian moon Ganymede, the elaboration
the radio emission spectrum of the Jovian moon Callisto,
say nothing of the spectacular views of Mercury and Jupi
(and their magnetospheres) presented by the Mariner 10 a
Pioneer 11 experiments. Comparable advances were
ported in subsequent meetings.

In all the flurry and excitement of recent discoveries,
general view of the origin and evolution of the planets
yet emerged, but the subject is now very rich in provocat
hints and clever surmises. It is becoming clear that the stu
of any planet illuminates our knowledge of the rest, an
we are to understand Earth thoroughly, we must hav
comprehensive knowledge of the other planets.
example, one now fashionable suggestion, which I f
proposed in 1960, is that the high temperatures on
surface of Venus are due to a runaway greenhouse effec
which water and carbon dioxide in a planetary atmosph
impede the emission of thermal infrared radiation from
surface to space; the surface temperature then rises

ieve equilibrium between the visible sunlight arriving at surface and the infrared radiation leaving it; this higher face temperature results in a higher vapour pressure of greenhouse gases, carbon dioxide and water; and so on, il all the carbon dioxide and water vapour is in the our phase, producing a planet with high atmospheric ssure and high surface temperature.

Now, the reason that Venus has such an atmosphere and rth does not seems to be a relatively small increment of light. Were the Sun to grow brighter or Earth's surface d clouds to grow darker, could Earth become a replica of classical vision of Hell? Venus may be a cautionary tale our technical civilization, which has the capability to er profoundly the environment of Earth.

Despite the expectation of almost all planetary scientists, rs turns out to be covered with thousands of sinuous butaried channels probably several billion years old. hether formed by running water or running CO_2, many ch channels probably could not be carved under present nospheric conditions; they require much higher pressures d probably higher polar temperatures. Thus the channels s well as the polar laminated terrain on Mars – may re witness to at least one, and perhaps many, previous ochs of much more clement conditions, implying major matic variations during the history of the planet. We do t know if such variations are internally or externally sed. If internally, it will be of interest to see whether the rth might, through the activities of man, experience a artian degree of climatic excursions – something much ater than the Earth seems to have experienced at least ently. If the Martian climatic variations are externally oduced – for example, by variations in solar luminosity then a correlation of Martian and terrestrial paleo-matology would appear extremely promising.

Mariner 9 arrived at Mars in the midst of a great global

dust storm, and the Mariner 9 data permit an observatio test of whether such storms heat or cool a planetary surf Any theory with pretensions to predicting the clim consequences of increased aerosols in the Earth's atm phere had better be able to provide the correct answer the global dust storm observed by Mariner 9. Draw upon our Mariner 9 experience, James Pollack of NA Ames Research Center, Brian Toon of Cornell and I h calculated the effects of single and multiple volcanic plosions on the Earth's climate and have been able reproduce, within experimental error, the observed clim effects after major explosions on our planet. The perspec of planetary astronomy, which permits us to view a plane a whole, seems to be very good training for studies of Earth. As another example of this feedback from planet studies on terrestrial observations, one of the major gro studying the effect on the Earth's ozonosphere of the of halocarbon propellants from aerosol cans is headed M. B. McElroy at Harvard University – a group that cu teeth for this problem on the aeronomy of the atmosph of Venus.

We now know from space-vehicle observations someth of the surface density of impact craters of different sizes Mercury, the Moon, Mars and its satellites; radar stu are beginning to provide such information for Venus, a although it is heavily eroded by running water and tecto activity, we have some information about craters on surface of the Earth. If the population of objects produc such impacts were the same for all these planets, it mi then be possible to establish both an absolute and a relat chronology of cratered surfaces. But we do not yet kn whether the populations of impacting objects are commo all derived from the asteroid belt, for example – or local; example, the sweeping up of rings of debris involved in final stages of planetary accretion.

The heavily cratered lunar highlands speak to us of an
y epoch in the history of the solar system when cratering
much more common than it is today; the present
ulation of interplanetary debris fails by a large factor to
ount for the abundance of the highland craters. On the
er hand, the lunar maria have a much lower crater
ndance, which can be explained by the present popula-
of interplanetary debris, largely asteroids and possibly
d comets. It is possible to determine, for planetary
faces that are not so heavily cratered, something of the
olute age, a great deal about the relative age, and in
ne cases, even something about the distribution of sizes
he population of objects that produced the craters. On
rs, for example, we find the flanks of the large volcanic
untains are almost free of impact craters, implying their
nparative youth; they were not around long enough to
umulate very much in the way of impact scars. This is
basis for the contention that volcanoes on Mars are a
nparatively recent phenomenon.

The ultimate objective of comparative planetology is, I
pose, something like a vast computer programme into
ch we put a few input parameters – perhaps the initial
s, composition, angular momentum and population of
ghbouring impacting objects – and out comes the time
lution of the planet. We are very far from having such a
p understanding of planetary evolution at the present
e, but we are much closer than would have been thought
sible only a few decades ago.

Every new set of discoveries raises a host of questions
ch we were never before wise enough even to ask. I will
ntion just a few of them. It is now becoming possible
compare the compositions of asteroids with the compo-
ons of meteorites on Earth (see Chapter 15). Asteroids
n to divide neatly into silicate-rich and organic-matter-
objects. One immediate consequence appears to be that

the asteroid Ceres is apparently undifferentiated, while t
less massive asteroid Vesta is differentiated. But our prese
understanding is that planetary differentiation occurs abo
a certain critical mass. Could Vesta be the remnant of a mu
larger parent body now gone from the solar system? T
initial radar glimpse of the craters of Venus shows them
be extremely shallow. Yet there is no liquid water to ero
the Venus surface, and the lower atmosphere of Venus see
to be so slow-moving that dust may not be able to fill t
craters. Could the source of the filling of the craters of Ven
be a slow molasses-like collapse of a very slightly molt
surface?

The most popular theory on the generation of planeta
magnetic fields invokes rotation-driven convection curre
in a conducting planetary core. Mercury, which rotates on
every fifty-nine days, was expected in this scheme to ha
no detectable magnetic field. Yet such a field is manifes
there, and a serious reappraisal of theories of planeta
magnetism is in order. Only Saturn and Uranus have rin
Why? There is on Mars an exquisite array of longitudin
sand dunes nestling against the interior ramparts of a lar
eroded crater. There is in the Great Sand Dunes Nation
Monument near Alamosa, Colorado, a very similar set
sand dunes nestling in the curve of the Sangre de Cris
mountains. The Martian and the terrestrial sand dunes ha
the same total extent, the same dune-to-dune spacing and t
same dune heights. Yet the Martian atmospheric pressure
1/200 that on Earth, the winds necessary to initiate t
saltation of sand grains are ten times that for Earth, a
the particle-size distribution may be different on the tw
planets. How, then, can the dune fields produced by win
blown sand be so similar? What are the sources of t
decametre radio emission on Jupiter, each less than 1
kilometres across, fixed on the Jovian surface, which inte
mittently radiate to space?

Mariner 9 observations imply that the winds on Mars at
t occasionally exceed half the local speed of sound. Are
winds ever much larger? What is the nature of a transonic
eorology? There are pyramids on Mars about 3
metres across at the base and 1 kilometre high. They are
kely to have been constructed by Martian pharaohs.
rate of sandblasting by wind-transported grains on
s is at least 10,000 times that on Earth because of the
ter speeds necessary to move particles in the thinner
rtian atmosphere. Could the facets of the Martian
amids have been eroded by millions of years of such
dblasting from more than one prevailing wind direction?
he moons in the outer solar system are almost certainly
replicas of our own, rather dull satellite. Many of them
e such low densities that they must be composed largely
nethane, ammonia or water ices. What will their surfaces
t like close up? How will impact craters erode on an icy
face? Might there be volcanoes of solid ammonia with a
of liquid NH_3 trickling down the sides? Why is Io, the
rmost large satellite of Jupiter, enveloped in a cloud of
ous sodium? How does Io help to modulate the syn-
otron emission from the Jovian radiation belt in which it
s? Why is one side of Iapetus, a moon of Saturn, six
es brighter than the other? Because of a particle-size
erence? A chemical difference? How did such differences
ome established? Why on Iapetus and nowhere else in the
r system in so symmetrical a way?

he gravity of the solar system's largest moon, Titan, is
low and the temperature of its upper atmosphere
iciently high that hydrogen should escape into space
emely rapidly in a process known as blow-off. But the
troscopic evidence suggests that there is a substantial
ntity of hydrogen on Titan. The atmosphere of Titan is a
tery. And if we go beyond the Saturnian system, we
roach a region in the solar system about which we know

almost nothing. Our feeble telescopes have not even relia
determined the periods of rotation of Uranus, Neptune a
Pluto, much less the character of their clouds and atm
pheres, and the nature of their satellite systems. The p
Diane Ackerman of Cornell University writes: 'Neptu
is/elusive as a dappled horse in fog. Pulpy?/Belt
Vapory? Frost-bitten? What we know/wouldn't/fill/a lemu
fist.'

One of the most tantalizing issues that we are j
beginning to approach seriously is the question of orga
chemistry and biology elsewhere in the solar system. T
Martian environment is by no means so hostile as to exclu
life, nor do we know enough about the origin and evoluti
of life to guarantee its presence there or anywhere else. T
question of organisms both large and small on Mars
entirely open, even after the Viking missions.

The hydrogen-rich atmospheres of places such as Jupit
Saturn, Uranus and Titan are in significant respects simi
to the atmosphere of the early Earth at the time of t
origin of life. From laboratory simulation experiments
know that organic molecules are produced in high yi
under such conditions. In the atmospheres of Jupiter a
Saturn the molecules will be convected to pyrolytic dept
But even there the steady-state concentration of orga
molecules can be significant. In all simulation experime
the application of energy to such atmospheres produces
brownish polymeric material, which in many significa
respects resembles the brownish colouring material in th
clouds. Titan may be completely covered with a brownis
organic material. It is possible that the next few years w
witness major and unexpected discoveries in the infa
science of exobiology.

The principal means for the continued exploration of t
solar system over the next decade or two will surely
unmanned planetary missions. Scientific space vehicles ha

been launched successfully to all the planets known to ancients. There is a range of unapproved proposed ions that have been studied in some detail. (See Chapter If most of these missions are actually implemented, it ear that the present age of planetary exploration will inue brilliantly. But it is by no means clear that these idid voyages of discovery will be continued, at least by United States. Only one major planetary mission, the leo project to Jupiter, has been approved in the last n years – and even it is in jeopardy.

ven a preliminary reconnaissance of the entire solar m out to Pluto and a more detailed exploration of a planets by, for example, Mars rovers and Jupiter entry es will not solve the fundamental problem of solar m origins; what we need is the discovery of other solar ems. Advances in ground-based and spaceborne tech- es in the next two decades might be capable of detecting ns of planetary systems orbiting nearby single stars. nt observational studies of multiple-star systems by nut Abt and Saul Levy, both of Kitt Peak National rvatory, suggest that as many as one-third of the stars e sky may have planetary companions. We do not know ther such other planetary systems will be like ours or on very different principles.

e have entered, almost without noticing, an age of oration and discovery unparalleled since the Renais- e. It seems to me that the practical benefits of compara- planetology for Earthbound sciences; the sense of nture imparted by the exploration of other worlds to a ety that has almost lost the opportunity for adventure; philosophical implications of the search for a cosmic pective – these are what will in the long run mark our . Centuries hence, when our very real political and social lems may be as remote as the very real problems of the of the Austrian Succession seem to us, our time may be

remembered chiefly for one fact: this was the age when
inhabitants of the Earth first made contact with the cos
around them.

CHAPTER 11

A PLANET NAMED GEORGE

* * *

And teach me how
To name the bigger light, and how the less,
That burn by day and night ...

WILLIAM SHAKESPEARE,
The Tempest, Act I, Scene 2

'Of course they answer to their names?'
the Gnat remarked carelessly.
'I never knew them to do it,' [said Alice.]
'What's the use of their having names,'
said the Gnat, 'if they won't answer to them?'

LEWIS CARROLL,
Through the Looking Glass

E IS ON the Moon a small impact crater called Galilei. ıbout 9 miles across, roughly the size of the Elizabeth, Jersey, greater metropolitan area, and is so small that a ·ized telescope is required to see it at all. Near the centre at side of the moon which is perpetually turned towards Earth is a splendid ancient battered ruin of a crater, miles across, called Ptolemaeus; it is easily seen with expensive set of field glasses and can even be made out, ersons of keen eyesight, with the naked eye.

olemy (second century A.D.) was the principal advocate e view that our planet is immovable and at the centre e universe; he imagined that the Sun and the planets d the Earth once daily, imbedded in swift crystalline es. Galileo (1564–1642), on the other hand, was a

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leading supporter of the Copernican view that it is the
which is at the centre of the solar system and that the E
is one of many planets revolving around it. Moreover, it
Galileo who, by observing the crescent phase of Ve
provided the first convincing observational evidence
favour of the Copernican view. It was Galileo who
called attention to the existence of craters on our nat
satellite. Why, then, is crater Ptolemaeus so much m
prominent on the moon than crater Galileo?

The convention of naming lunar craters was establis
by Johannes Höwelcke, known by his Latinized name
Hevelius. A brewer and town politican in Danzig, Heve
devoted a great deal of time to lunar cartography, publish
a famous book, *Selenographia*, in 1647. Having hand-etc
the copper plates used for printing his maps of the telesco
appearance of the Moon, Hevelius was faced with
question of what to name the features depicted. So
proposed naming them after Biblical personages; oth
advocated philosophers and scientists. Hevelius felt t
there was no logical connection between the features on
Moon and the patriarchs and prophets of thousands
years earlier, and he was also concerned that there might
substantial controversy about which philosophers a
scientists – particularly if they were still alive – to hono
Taking a more prudent course, he named the promin
lunar mountains and valleys after comparable terrest
features: as a result we have lunar Apennines, Pyrene
Caucasus, Juras and Atlas mountains and even an Alp
valley. These names are still in use.

Galileo's impression was that the dark, flat areas on
moon were seas, real watery oceans, and that the bright a
rougher regions densely studded with craters were co
tinents. These maria (Latin for 'seas') were named prima
after states of mind or conditions of nature: Mare Frigo
(the Sea of Cold), Lacus Somniorum (the Lake of Dream

Crisium (the Sea of Crises), Sinus Iridum (the Bay of
ɔows), Mare Serenitatis (the Sea of Serenity), Oceanus
llarum (the Ocean of Storms), Mare Nubium (the Sea
ɔuds), Mare Fecunditatis (the Sea of Fertility), Sinus
um (the Bay of Billows), Mare Imbrium (the Sea of
;) and Mare Tranquillitatis (the Sea of Tranquillity) –
tic and evocative collection of place names, particularly
ɔ inhospitable an environment as the Moon. Un-
nately, the lunar maria are bone-dry, and samples
ned from them by the US Apollo and Soviet Luna
ɔns imply that never in their past were they filled with
. There never were seas, bays, lakes or rainbows on the
n. These names have survived to the present. The first
craft to return data from the surface of the Moon,
2, touched down in Mare Imbrium; and the first
n beings to make landfall on our natural satellite, the
nauts of Apollo 11, did so, ten years later, in Mare
quillitatis. I think Galileo would have been surprised
pleased.

spite Hevelius' misgivings, the lunar craters were
d after scientists and philosophers by Giovanni
sta Riccioli in a 1651 publication, *Almagestum Novum*.
itle of the book means 'The New Almagest', the old
gest having been the life's work of Ptolemy. ('Alma-
a modest title, means 'The Greatest' in Arabic.)
oli simply published a map on which he placed his
nal preferences for crater names, and the precedent
many of his choices have been followed without
ion ever since. Riccioli's book came out nine years
the death of Galileo, and there has certainly been
uate opportunity to rename craters later. Nevertheless,
nomers have retained this embarrassingly ungenerous
nition of Galileo. Twice as large as crater Galileo is one
l Hell after the Jesuit father Maximilian Hell.

ie of the most striking of the lunar craters is Clavius,

142 miles in diameter and the site of a fictional lunar bas the movie *2001: A Space Odyssey*. Clavius is the Latini name of Christoffel Schlüssel (= 'key' in Germar Clavius), another member of the Jesuit order, and a s porter of Ptolemy. Galileo engaged in a protracted c troversy on the priority of discovery and the nature sunspots with yet another Jesuit priest, Christop Scheiner, which developed into a bitter personal antagoni and which is thought by many historians of science to h contributed to the house arrest of Galileo, the proscript of his books, and his confession, extracted under threat torture by the Inquisition, that his previous Copernic writings were heretical and that Earth did not mo Scheiner is commemorated by a lunar crater 70 miles acro And Hevelius, who objected altogether to the naming lunar features after people, has a handsome crater nam after himself.

Riccioli gave the names Tycho, Kepler and, interesting Copernicus to three of the most prominent craters on Moon. Riccioli himself and his student Grimaldi recei large craters at the limb, or edge, of the moon, Riccio being 106 miles across. Another prominent crater is nam Alphonsus after Alphonso X of Castile, a thirteenth-centu Spanish monarch who had commented, after witnessing complexity of the Ptolemaic system, that had he be present at the Creation, he could have given God so useful suggestions on ordering the universe. (It is amusing imagine Alphonso X's response were he to learn that sev hundred years later a nation across the Western ocean wo send an engine called Ranger 9 to the Moon, automatica producing images of the lunar surface as it descended, u finally it crashed in a pre-existing depression named, af His Castilian Majesty, Alphonsus.) A somewhat less pro nent crater is named after Fabricius, the Latinized name David Goldschmidt, who in 1596 discovered that the s

ı varied periodically in brightness, striking another blow
nst the view championed by Aristotle and supported by
Church that the heavens were unchanging.

hus the prejudice against Galileo in seventeenth-century
did not, in the naming of lunar features, carry over as a
pletely consistent bias in favour of Church fathers and
rch doctrines on matters astronomical. Of the approxi-
ly seven thousand designated lunar formations it is
ult to extract any consistent pattern. There are craters
ed after political figures who had little direct or apparent
nection with astronomy, such as Julius Caesar and
er Wilhelm I, and after individuals of heroic obscurity:
xample, crater Wurzelbaur (50 miles in diameter) and
r Billy (31 miles in diameter). Most of the designations
mall lunar craters are derived from large and nearby
rs, as, for example, near the crater Mösting are the
ller craters Mösting A, Mösting B, Mösting C, and so
A wise prohibition against naming craters after living
viduals has been breached only occasionally, as in
gning a few quite small craters to American astronauts
ıe Apollo lunar missions, and by a curious symmetry in
age of détente, to Soviet cosmonauts who remained
ind in Earth orbit.

ı this century an attempt has been made to name,
sistently and coherently, surface features and other
tial objects by giving this function to special commis-
s of the International Astronomical Union (IAU), the
ınization of all professional astronomers on the planet
h. A previously unnamed bay of one of the lunar 'seas',
nined in detail by the American Ranger spacecraft, was
ially designated Mare Cognitum (the Known Sea). It is
ıme not so much of quiet satisfaction as of jubilation.
J deliberations have not always been easy. For example,
n the first – somewhat indistinct – photographs of the far
of the Moon were returned by the historically important

Luna 3 mission, the Soviet discoverers wished to name long, bright marking on their photographs 'The Sov Mountains'. Since there is no major terrestrial mounta range of this name, the suggestion was in conflict with t Hevelius convention. It was accepted, nevertheless, homage to the remarkable feat of Luna 3. Unfortunate subsequent data suggest that the Soviet Mountains are n mountains at all.

In a related instance, Soviet delegates proposed nami one of the two maria on the lunar far side (both very sm compared with those on the near side) Mare Moscovien (the Sea of Moscow). But Western astronomers object that this again departed from tradition because Mosc was neither a condition of nature nor a state of mind. was pointed out in response that the most recent namings lunar maria – those on the limbs, which are difficult make out with ground-based telescopes – have not qu followed this convention either: as Mare Marginis (t Marginal Sea), Mare Orientale (the Eastern Sea) and Ma Smythii (the Smyth Sea). Perfect consistency having alrea been breached, the issue was decided in favour of the Sov proposal. At an IAU meeting in Berkeley, California, 1961, it was officially ruled by Audouin Dollfus of Fran that Moscow is a state of mind.

The advent of space exploration has now multipli manyfold the problems of solar system nomenclature. A interesting example of the emerging trend can be found in t naming of features on Mars. Bright and dark surfa markings on the Red Planet have been viewed, recorded a mapped from Earth for several centuries. While the natu of the markings was unknown there was an irresistib temptation to name them nevertheless. Following sever abortive attempts to name them after astronomers who h studied Mars, G. V. Schiaparelli in Italy and E. M Antoniadi, a Greek astronomer who worked in Franc

blished around the turn of the twentieth century the ·ention of naming Martian features after allusions to ;ical mythological personages and place names. Thus ıave Thoth-Nepenthes, Memnonia, Hesperia, Mare :um (the Northern Sea) and Mare Acidalium (the Sour , as well as Utopia, Elysium, Atlantis, Lemuria, Eos ·vn) and Uchronia (which, I suppose, can be translated ·ood Times). In 1890, scholarly people were much more fortable with classical myth than they are today.

KALEIDOSCOPIC surface of Mars was first revealed by :rican spacecraft of the Mariner series, but chiefly by ·iner 9, which orbited Mars for a full year, beginning ;ovember 1971, and radioed back to Earth more than 0 close-up photographs of its surface. A profusion of :pected and exotic detail was uncovered, including :ring volcanic mountains, craters of the lunar sort but h more heavily eroded, and enigmatic, sinuous valleys :h were probably caused by running water at previous :hs in the history of the planet. These new features l out for names, and the IAU dutifully appointed a mittee under the chairmanship of Gerard de Vau- :eurs of the University of Texas to propose a new tian nomenclature. Through the efforts of several of us ıe Martian nomenclature committee, a serious attempt made to deprovincialize the new names. It was impossible revent major craters being named after astronomers who studied Mars, but the range of occupations and ·onalities could be significantly broadened. Thus there Martian craters larger than 60 miles across named after Chinese astronomers Li Fan and Liu Hsin; after ɔgists such as Alfred Russel Wallace, Wolf Vishniac, . Vinogradsky, L. Spallanzani, F. Redi, Louis Pasteur, . Muller, T. H. Huxley, J. B. S. Haldane and Charles win; after a handful of geologists such as Louis Agassiz,

Alfred Wegener, Charles Lyell, James Hutton and E. Sue and even after a few science fiction writers such as Edg Rice Burroughs, H. G. Wells, Stanley Weinbaum and Jo W. Campbell, Jr. There are also two large craters on Ma named Schiaparelli and Antoniadi.

But there are many more cultures on the planet Earth even ones with identifiable astronomical traditions – th are represented by any such list of individual names. In attempt to offset at least in part this implicit cultural bia a suggestion of mine was accepted to call the sinuous valle after the names of Mars in other, largely non-Europe languages. Below is a table of the most prominent. a curious coincidence Ma'adim (Hebrew) and Al Qahi (Arabic: the war god after whom Cairo is named) are che by jowl. The landing site for the first Viking spacecraft w in Chryse, near the confluence of the Ares, Tiu, Simud a Shalbatana valleys.

TABLE 1
THE FIRST MARTIAN CHANNELS TO BE NAMED

Name	*Language*
Al Qahira	Egyptian Arabic
Ares	Greek
Auqakuh	Quechua (Inca)
Huo Hsing	Chinese
Ma'adim	Hebrew
Mangala	Sanskrit
Nirgal	Babylonian
Kasei	Japanese
Shalbatana	Akkadian
Simud	Sumerian
Tiu	Old English

or the massive Martian volcanoes, one suggestion was to
e them after major terrestrial volcanoes, such as
rongoro or Krakatoa, which would permit some
arance on Mars of cultures with no written astro-
ical tradition. But this was objected to on the ground
there would be confusion when comparing terrestrial
Martian volcanoes: Which Ngorongoro are we talking
t? The same potential problem exists for terrestrial
, but we seem able to compare Portland, Oregon,
Portland, Maine, without becoming hopelessly con-
l. Another suggestion, made by a European savant, was
ame each volcano 'Mons' (mountain) followed by the
e of a principal Roman deity in the appropriate Latin
ive case: thus, Mons Martes, Mons Jovis and Mons
ris. I objected that at least the last of these had been
empted by quite a different field of human activity. The
was: 'Oh, I hadn't heard.' The outcome was to name
Martian volcanoes after adjacent bright and dark
kings in the classical nomenclature. We have Pavonis
is, Elysium Mons and – satisfyingly, for the largest
ano in the solar system – Olympus Mons. Thus, while
olcano names are very much in the Western tradition,
nd large the most recent Mars nomenclature represents
nificant break with tradition: an important number of
ires have been named neither after evocations of
ical times nor after European geographical features and
teenth-century Western visual astronomers.

me Martian and lunar craters are named after the same
viduals. This is the Portland case again, and I think it
cause very little confusion in practice. It does have at
one salutary benefit: on Mars there is today a large
r named Galileo. It is about the same size as the one
ed Ptolemaeus. And there are no craters on Mars named
iner or Riccioli.

nother unexpected consequence of the Mariner 9

mission is that the first close-up photographs of the moo
of another planet were obtained. Maps now exist whi
show about half the surface features on the two Marti
moons, Phobos and Deimos (the attendants of the war go
Mars). A subcommittee on Mars satellite nomenclatu
which I chaired assigned craters on Phobos to astronome
who had studied the moons. A prominent crater at Phob
south pole is named after Asaph Hall, the discoverer of bo
moons. Astronomical apocrypha has it that Hall was on t
verge of giving up his search for the Martian moons wh
he was directed by his wife to return to the telescope. H
promptly discovered them and named them 'fear' (Phobo
and 'terror' (Deimos). Accordingly, the largest crater
Phobos was given Mrs. Hall's maiden name, Angeli
Stickney. Had the impacting object that excavated crat
Stickney been any larger, it probably would have shattere
Phobos.

Deimos is reserved for writers and others who were
some way involved with speculations about the moons
Mars. The two most prominent features are named aft
Jonathan Swift and Voltaire, who, in their speculati
romances, *Gulliver's Travels* and *Micromégas*, respectivel
prefigured before the actual discovery the existence of tw
moons around Mars. I wanted to name a third Deimon
crater after René Magritte, the Belgian surrealist who
paintings 'Le Château des Pyrénées' and 'Le Sens de Réalit
pictured large rocks, suspended in the sky, of an aspe
astonishingly like the two Martian moons – except for th
presence in the first painting of a castle, which, so far as w
know, does not surmount Phobos. The suggestion wa
however, voted down as frivolous.

THIS IS THE moment in history when the features on th
planets will be named forever. A crater name represents
substantial memorial: the estimated lifetime of large luna

artian and Mercurian craters is measured in billions of
ars. Because of the enormous recent increase in the number
surface features that need to be named – and also because
e names of almost all dead astronomers have already been
en to one or another celestial object – a new approach is
eded. At the IAU meeting in Sydney, Australia, in 1973,
eral committees were appointed to look into questions of
netary nomenclature. One clear problem is that if craters
other planets are now named after a category other than
ople, we will be left with only the names of astronomers
d a few others on the Moon and planets. It would be
arming to name craters on, say, Mercury, after birds or
tterflies, or cities or ancient vehicles of exploration and
covery. But if we accept this course, we will leave the
pression on globes and maps and textbooks that we
eem only astronomers and physicists; that we care
thing for poets, composers, painters, historians, archae-
ogists, playwrights, mathematicians, anthropologists,
ulptors, physicians, psychologists, novelists, molecular
logists, engineers and linguists. The proposal that such
lividuals be commemorated with unassigned lunar craters
uld result, say, in Dostoevsky or Mozart or Hiroshige
igned craters a tenth of a mile across, while Pitiscus is
miles in diameter. I do not think this would speak well
the breadth of vision and intellectual ecumenicism of
e name-givers.

After a protracted debate this point of view has prevailed
n significant part due to its vigorous support by Soviet
ronomers. Accordingly, the Mercury nomenclature com-
ttee, under the chairmanship of David Morrison of the
iversity of Hawaii, has decided to name Mercurian
pact craters after composers, poets and authors. Thus,
jor craters are named Johann Sebastian Bach, Homer
d Murasaki. It is difficult for a committee of largely
estern astronomers to select a group of names representa-

tive of all of world culture, and Morrison's committe requested help from appropriate musicians and experts i comparative literature. The most vexing problem is to find for example, the names of those who composed Han dynast music, cast Benin bronzes, carved Kwakiutl totem pole and compiled Melanesian folk epics. But even if such information comes in slowly, there will be time: the Marine 10 photography of Mercury, which discovered the feature to be named, covered only half the surface of the planet, an it will be many years before the craters in the other hemi sphere will be photographed and named.

In addition, there are a few objects on Mercury that hav been recommended for other sorts of names for specia purposes. The proposed 20° meridian of longitude passe through a small crater which the Mariner 10 televisio experimenters have suggested calling Hun Kal, the Azte word for 'twenty', the base of Aztec arithmetic. And the have suggested calling an enormous depression, in som senses comparable to a lunar mare, the Caloris basin Mercury is very hot. Finally, all of these names apply only t the topographic features of Mercury; the bright and dar markings, glimpsed dimly by past generations of ground based astronomers, have not yet been mapped reliably When they are, there will probably be new suggestions fo naming them. Antoniadi proposed names for such feature on Mercury, some of which – such as Solitudo Herma Trismegisti (the solitude of Hermes, the thrice-great) – hav a fine ring and perhaps will ultimately be retained.

NO PHOTOGRAPHIC maps of the surface of Venus exis because the planet is perpetually enshrouded by opaqu clouds. Nevertheless, surface features are being mapped b ground-based radar. Already it is apparent that there ar craters and mountains, and other topographical features o stranger aspect. The success of the Venera 9 and 10 space

ft in obtaining photographs of the planet's surface gests that some day photographs may be returned from raft or balloons in the lower Venus atmosphere.

he first prominent features discovered on Venus, regions ily reflective to radar, were given unassuming names n as Alpha, Beta and Gamma. The present Venus nomen- ure committee, under the chairmanship of Gordon engill of the Massachusetts Institute of Technology, poses two categories of names for Venus surface features. e category would be pioneers in radio technology whose rk led to the development of the radar techniques that mit mapping the surface of Venus: for example, Faraday, xwell, Heinrich Hertz, Benjamin Franklin and Marconi. e other category, suggested by the name of the planet f, would be women. At first glance, the idea of a planet oted to women may appear sexist. But I think the osite is true. For historical reasons, women have been couraged from pursuing the sorts of occupations now ng memorialized on other planets. The number of women r whom craters have so far been named is very small: odowska (Madame Curie's maiden name); Stickney; the onomer Maria Mitchell; the pioneer nuclear physicist a Meitner; Lady Murasaki; and only a few others. While the occupational rules for other planets women's names continue to appear occasionally on other planetary aces, the Venus proposal is the only one that permits quate recognition to be made of the historical contri- ion of women. (I am glad, however, that this idea will be applied consistently; I would not myself want to see rcury covered with businessmen and Mars with generals.) n a fashion, women have traditionally been com- morated in the asteroid belt (see Chapter 15), that ection of rocky and metallic boulders which circle the n between the orbits of Mars and Jupiter. With the eption of a category of asteroids named after heroes of

the Trojan War, it used to be that all asteroids were name after women. First it was largely women of classic mythology, such as Ceres, Urania, Circe and Pandora. A available goddesses dwindled, the scope broadened t include Sappho, Dike, Virginia and Sylvia. Then, as th floodgates of discovery opened and the names of astron omers' wives, mothers, sisters, mistresses and great-aun were exhausted, they took to naming asteroids after real c hoped-for patrons and others, with a female endin appended, as, for example, Rockefelleria. By now more tha two thousand asteroids have been discovered, and th situation has become moderately desperate. But non Western traditions have hardly been tapped, and there ar a multitude of Basque, Amharic, Ainu, Dobu and Kun feminine names for future asteroids. In anticipation of a Egyptian-Israeli détente, Eleanor Helin of the Californi Institute of Technology proposed calling an asteroid sh discovered Ra-Shalom. An additional problem – or oppo tunity, depending on how one views it – is that we ma soon obtain close-up photographs of asteroids, with surfac details that will cry out to be named.

Beyond the asteroid belt, on the planets and large moon of the outer solar system, no nondescriptive names hav so far been bestowed. Jupiter, for example, has a Great Re Spot and a North Equatorial Belt, but no feature called say, Smedley. The reason is that when we see Jupiter w are looking at its clouds, and it would not be a very fittin or at least not a very long-lived memorial to Smedley t name a cloud after him. Instead, the present major questio on nomenclature in the outer solar system is what to nam the moons of Jupiter. The moons of Saturn, Uranus an Neptune have satisfying or at least obscure classical name (see Table 2). But the situation for the fourteen moons o Jupiter is different.

The four large moons of Jupiter were discovered b

TABLE 2
NAMES OF THE SATELLITES
OF THE OUTER PLANETS

Saturn	*Neptune*
Janus	Triton
Mimas	Nereid
Enceladus	
Tethys	*Uranus*
Dione	Miranda
Rhea	Ariel
Titan	Umbriel
Hyperion	Titania
Iapetus	Oberon
Phoebe	
	Pluto
	Charon

ileo, whose theological contemporaries were convinced a vague amalgam of Aristotelian and Biblical ideas that other planets could have no moons. The contrary overy by Galileo was disconcerting to fundamentalist rchmen of the time. Possibly in an effort to circumvent icism, Galileo called the moons the Medicean satellites – r his funding agency. But posterity has been wiser: they known instead as the Galilean satellites. In a similar , when William Herschel of England discovered the nth planet he proposed calling it George. If wiser heads not prevailed, we might today have a major planet ned after George III. Instead we call it Uranus.

he Galilean satellites were assigned their Greek mythocal names by Simon Marius (commemorated on the on by a crater 27 miles across), a contemporary of ileo and a disputant with him for the priority of their overy. Marius and Johannes Kepler felt that it would

be extremely unwise to name celestial objects after rea people and particularly after political personages. Mariu wrote: 'I want the thing done without superstition and wit the sanction of theologians. Jupiter especially is charged b the poets with illicit loves. Especially well-known amon these are three virgins, whose love Jupiter secretly covete and obtained, namely: Io ... Callisto ... and Europa .. Yet even more ardently did he love the beautiful bo Ganymede ... and so I believe that I have not done badl in the naming the first Io, the second Europa, the third, o account of the splendour of its light, Ganymede, and lastl the fourth Callisto.'

However, in 1892 E. E. Barnard discovered a fifth moo of Jupiter with an orbit interior to Io's. Barnard resolutel insisted that this satellite should be called Jupiter 5 and b no other name. Since then, Barnard's position has bee maintained, and of the fourteen Jovian moons now known only the Galilean satellites had, until recently, name officially sanctioned by the IAU. However unreasonable i may be, people show a strong preference for names ove numbers. (This is clearly illustrated in the resistance o college students to being considered 'only a number' by th college bursar; by the outrage of many citizens at bein known to the government only by their social securit number; and by the systematic attempts in jails and priso camps to demoralize and degrade the inmates by assignin them a numeral as their only identity.) Soon after Barnard' discovery, Camille Flammarion suggested the nam Amalthea for Jupiter 5 (Amalthea was in Greek legend th goat that suckled the infant Zeus). While being suckled by goat is not precisely an act of illicit love, it must have seemed to the Gallic astronomer, adequately close.

The IAU committee on Jovian nomenclature, chaired b Tobias Owen of the State University of New York at Ston Brook, has proposed a set of names for Jupiter 6 throug

Two principles guided their selection: the name chosen
uld be that of 'an illicit love' of Jupiter, but one so
ure as to have been missed by those indefatigable cullers
ne classics who name asteroids, and must end with an
and *e* depending on whether the moon goes around
ter clockwise or counterclockwise. But in the opinion of
ast some classical scholars, these names are obscure to
oint of bewilderment, and the result leaves many of the
t prominent Jovian paramours unrepresented in the
ter system. The result is particularly poignant in that
a (Juno), the wife so often scorned by Zeus (Jupiter), is
represented at all. Evidently, she was inadequately
t. An alternative list of names, which includes most of
prominent paramours as well as Hera, is also shown in
able on page 216. Were these names employed, it is true
would duplicate asteroid names. This is in any case
ady a fact for the four Galilean satellites, where the
unt of confusion thus engendered has been negligible.
the other hand, there are those who support Barnard's
tion that numbers are sufficient; prominent among these
harles Kowal* of the California Institute of Technology,
discoverer of Jupiter 13 and Jupiter 14. There seems to
nerit in all three positions and it will be interesting to
how the debate turns out. At least we do not yet have to
ge the merits of contending suggestions for naming
ures on the Jovian satellites.

ut that time is not long off. There are thirty-one known
ns of Jupiter, Saturn, Uranus and Neptune. None has
n photographed close up. The decision has recently been

Kowal has also recently discovered a very interesting small object
ing the Sun between the orbits of Uranus and Saturn. It may be the
st member of a new asteroid belt. Kowal proposes calling it Chiron,
the centaur who educated many Greek mythological gods and heroes.
ner trans-Saturnian asteroids are discovered, they can be named after
centaurs.

TABLE 3
PROPOSED NAMES FOR JOVIAN SATELLITES

Satellite	*I.A.U. Committee Names*	*Alternative Names Suggested Here*
J V	Amalthea	Amalthea
VI	Himalia	Maia
VII	Elara	Hera
VIII	Pasiphaë	Alcmene
IX	Sinope	Leto
X	Lysithea	Demeter
XI	Carme	Semele
XII	Anake	Danaë
XIII	Leda	Leda
XIV	—	—

made to name features on the moons in the outer sol
system after mythological figures from all cultures. Ho
ever, very soon the Voyager mission will obtain hig
resolution images of about ten of them, in addition to t
rings of Saturn. The total surface area of the small objec
in the outer solar system greatly exceeds the areas
Mercury, Venus, Earth, Moon, Mars, Phobos and Deim
together. There will be ample opportunity for all huma
occupations and cultures to be represented eventually, and
daresay provisions for nonhuman species can also be mad
There are probably more professional astronomers ali
today than in the total prior recorded history of mankind
suppose that many of us will also be commemorated in t
outer solar system – a crater on Callisto, a volcano
Titan, a ridge on Miranda, a glacier on Halley's comet
(Comets, incidentally, are given the names of their di
coverers.) I sometimes wonder what the arrangement w

whether those who are bitter rivals will be separated by
. placed on different worlds, and whether those whose
veries were collaborative will nestle together, crater
art to crater rampart. There have been objections that
cal philosophers are too controversial. I myself would
lighted to see two enormous, adjacent craters called
n Smith and Karl Marx. There are even enough objects
solar system for dead political and military leaders to
commodated. There are those who have advocated
orting astronomy by selling crater names to the highest
rs, but I think this goes rather too far.

E IS A curious problem about names in the outer solar
m. Many of the objects there have extremely low
ty, as if they were made of ice, great fluffy snowballs
or hundreds of miles across. While objects impacting
bodies will certainly produce craters, craters in ice will
ast very long. At least for some objects in the outer
system, named features may be transient. Perhaps that
good thing: it would give us a chance to revise our
ons of politicians and others, and will give eventual
rse if flushes of national or ideological fervour are
ted in solar system nomenclature. The history of
nomy shows that some suggestions for celestial nomen-
re are better ignored. For example, in 1688 Erhard
el at Jena proposed a revision of the ordinary zodiacal
ellations – the lion, virgin, fish and water carrier that
le have in mind when they ask you what 'sign' you are.
el proposed instead a 'heraldic sky' in which the royal
ies of Europe would be represented by their tutelary
als: a lion and a unicorn for England, for example. I
to imagine descriptive stellar astronomy today had that
been adopted in the seventeenth century. The sky would
arved into two hundred tiny patches, one for each
n-state existing at the time.

The naming of the solar system is fundamentally no task for the exact sciences. It has historically encounte prejudice and jingoism and lack of foresight at ev turn. However, while it may be a little early for s congratulation, I think astronomers have recently ta some major steps to deprovincialize the nomenclature make it representative of all of humanity. There are th who think it is a pointless, or at least thankless, task. some of us are convinced it is important. Our rem descendants will be using our nomenclature for their hom on the broiling surface of Mercury; by the banks of Martian valleys; on the slopes of Titanian volcanoes; or the frozen landscape of distant Pluto, where the Sun appe as a point of bright light in a sky of unremitting blackn Their view of us, of what we cherish and hold dear, m be determined largely by how we name the moons planets today.

CHAPTER 12

LIFE IN THE SOLAR SYSTEM

* * *

'I see nobody on the road,' said Alice.
'I only wish *I* had such eyes,' the King remarked in a
etful tone. 'To be able to see Nobody! And at that distance
o! Why, it's as much as *I* can do to see real people, by this
ght!'

LEWIS CARROLL,
Through the Looking Glass

THAN three hundred years ago, Anton van Leeuwen-
of Delft explored a new world. With the first micro-
he viewed a stagnant infusion of hay and was
nded to find it swarming with small creatures:

April 24th, 1676, observing this water by chance, I saw
with great wonder unbelievably very many small animal-
of various sorts; among others, some that were three to four
as long as broad. Their entire thickness was, in my judgement,
uch thicker than one of the little hairs that cover the body
use. These creatures had very short, thin legs in front of the
although I can recognize no head, I speak of the head for
ason that this part always went forward during movement)
se to the hindmost part lay a clear globule; and I judged that
ry hindmost part was slightly cleft. These animalcules are
ute while moving about, oftentimes tumbling all over.

tiny 'animalcules' had never before been seen by any
n being. Yet Leeuwenhoek had no difficulty in recog-
them as alive.
o centuries later Louis Pasteur developed the germ

theory of disease from Leeuwenhoek's discovery and laid
foundation for much of modern medicine. Leeuwenhoe
objectives were not practical at all, but exploratory a
adventuresome. He himself never guessed the future pr
tical applications of his work.

In May of 1974 the Royal Society of Great Britain hel
discussion meeting on 'The Recognition of Alien Life'. L
on Earth has developed by a slow, tortuous step-by-s
progression known as evolution by natural selecti
Random factors play a critical role in this process – as,
example, which gene at what time will be mutated
changed by an ultraviolet photon or a cosmic ray fr
space. All the organisms on Earth are exquisitely adapted
the vagaries of their natural environments. On some ot
planet, with different random factors operating and
tremely exotic environments, life may have evolved v
differently. If we landed a spacecraft on the planet Ma
for example, would we even be able to recognize the lo
life forms as alive?

One theme which was stressed at the Royal Soci
discussion was that life elsewhere should be recognizable
its improbability. Take trees, for example. Trees are lo
skinny structures, above ground fatter at the top than at
bottom. It is easy to see that after millennia of rubbing
wind and water, most trees should have fallen down. Th
are in mechanical disequilibrium. They are unlikely str
tures. Not all top-heavy structures are produced by biolo
There are, for example, pedestal rocks in deserts. But w
we to see a great many top-heavy structures, all clos
similar, we could make a reasonable guess that they w
of biological origin. Likewise for Leeuwenhoek's anim
cules. There are many of them, closely similar, hig
complex and improbable in the extreme. Without e
having seen them before, we correctly guess they
biological.

ere have been elaborate debates on the nature and ition of life. The most successful definitions invoke the tionary process. But we do not land on another planet vait to see if any nearby objects evolve. We do not have ime. The search for life then takes on a much more ical aspect. This point was brought out with some e at the Royal Society discussion when, after an nge remarkable for its rambling metaphysical vague- Sir Peter Medawar rose to his feet and said, 'Gentle- everyone in this room knows the difference between horse and a dead horse. Pray, therefore, let us cease ing the latter.' Medawar and Leeuwenhoek would have eye to eye.

t are there trees or animalcules on the other worlds of solar system? The simple answer is that no one yet s. From the vantage point of the nearest planets, it d be impossible to detect photographically the presence e on our own planet. Even from the closest orbital vations of Mars made to date, from the American craft Mariner 9 and Viking 1 and 2, details on Mars smaller than 100 metres across have remained in- le. Since even the most ardent enthusiasts of extra- strial life do not anticipate Martian elephants 100 es long, many important tests have not yet been rmed.

the present time we can only assess the physical onments of the other planets, determine whether they o severe as to exclude life – even forms rather different those we know on Earth – and in the case of the more ent environments perhaps speculate on the life forms might be present. The one exception is the Viking lander ts, briefly discussed below.

place may be too hot or too cold for life. If the eratures are very high – say, several thousands of es Centigrade – then the molecules that make up the

organism will fall to pieces. Thus it is customary to exclu the Sun as an abode of life. On the other hand, if t temperatures are too low, then the chemical reactions th drive the internal metabolism of the organism will proce at too ponderous a pace. For this reason the frigid was of Pluto are customarily excluded as an abode of li However, there may be chemical reactions which proceed respectable rates at low temperatures but which are u explored here on Earth, where chemists dislike working laboratories at −230 C. We must be careful not to take t chauvinistic a view of the matter.

The giant outer planets of the solar system, Jupit Saturn, Uranus, and Neptune, are sometimes excluded fro biological considerations because their temperatures a very low. But these temperatures are the temperatures their upper clouds. Deeper down in the atmospheres of su planets, as in the atmosphere of the Earth, much mo clement conditions are to be encountered. And they appe to be rich in organic molecules. By no means can they excluded.

While we human beings enjoy oxygen, this is hardly recommendation for it, since there are many organis that are poisoned by it. If the thin protective ozone lay in our atmosphere, made by sunlight from oxygen, did n exist, we would rapidly be fried by ultraviolet light from t Sun. But on other worlds, ultraviolet sunshades or biologic molecules impervious to near-ultraviolet radiation ca readily be imagined. Such considerations merely underli our ignorance.

An important distinction among the other worlds of o solar system is the thickness of their atmospheres. In t total absence of an atmosphere it is very difficult to concei of life. As on Earth, the biology on other planets must, think, be driven by sunlight. On our planet, the plants e the sunlight and the animals eat the plants. Were all t

nisms on Earth forced (by some unimaginable cata-
he) into a subterranean existence, life would cease as
as accumulated food stores were exhausted. The plants,
ndamental organisms on any planet, must see the Sun.
f a planet has no atmosphere, not only ultraviolet
tion but X-rays and gamma rays and charged particles
the solar wind will fall unimpeded on the planetary
ce and frizzle the plants.
rthermore, an atmosphere is necessary for exchange
aterials so that the basic molecules for biology are not
ed up. On Earth, for example, green plants give off
en – a waste product – into the atmosphere. Many
ring animals, like human beings, breathe the oxygen
ive off carbon dioxide, which the plants in turn imbibe.
out this clever (and painfully evolved) equilibrium
een plants and animals, we would rapidly run out of
en or carbon dioxide. For these two reasons – radiation
ction and molecular exchange – an atmosphere seems
red for life.
me of the worlds in our solar system have exceedingly
atmospheres. Our Moon, for example, has at its surface
han one million millionth the atmospheric pressure on
h. Six places on the near side of the Moon were
ined by Apollo astronauts. No top-heavy structures,
mbering beasts were found. Nearly four hundred kilo-
mes of samples have been returned from the Moon
neticulously examined in terrestrial laboratories. There
no animalcules, no microbes, almost no organic
icals, or even any water. We expected the Moon to be
ss, and apparently it is. Mercury, the closest planet to
un, resembles the Moon. Its atmosphere is exceedingly
and it ought not to support life. In the outer solar
m there are many large satellites the size of Mercury
ur own Moon, composed of some mix of rock (like
Moon and Mercury) and ices. Io, the second moon of

Jupiter, falls into this category. Its surface seems to b covered with a kind of reddish salt deposit. We are ve ignorant about it. But because of its very low atmospher pressure, we do not expect life on it.

Then there are planets with moderate atmospheres. Ear is the most familiar example. Here life has played a maj role in determining the composition of our atmosphere. Th oxygen is, of course, produced by green-plant photosy thesis, but even the nitrogen is thought to be made b bacteria. Oxygen and nitrogen together comprise 99 perce of our atmosphere, which has evidently been reworked on massive scale by the life on our planet.

The total pressure on Mars is about one half of o percent that on Earth, but the atmosphere there is compose largely of carbon dioxide. There are small quantities oxygen, water vapour, nitrogen and other gases. Th Martian atmosphere has not obviously been reworked b biology, but we do not know Mars well enough to exclu life there. It has congenial temperatures at some times an places, a dense enough atmosphere, and abundant wat locked away in the ground and polar caps. Even som varieties of terrestrial microorganisms can survive there ve well. Mariner 9 and Viking found hundreds of dry rive beds, apparently indicating a time in the recent geologic history of the planet when abundant liquid water flowed. is a world awaiting exploration.

A third and less familiar example of places with modera atmospheres is Titan, the largest moon of Saturn. Tita appears to have an atmosphere with a density between th of Mars and Earth. This atmosphere is, however, compose largely of hydrogen and methane, and is surmounted b an unbroken layer of reddish clouds – probably compl organic molecules. Because of its remoteness, Titan h attracted the interest of exobiologists only recently, but holds the promise of a long-term fascination.

The planets with very dense atmospheres present a special roblem. Like Earth, their atmospheres are cold at the top nd warmer at the bottom. But when the atmosphere is very ick, the temperatures at the bottom become too hot for ology. In the case of Venus, the surface temperatures are out 480°C; for the Jovian planets, many thousands of egrees Centigrade. All these atmospheres, we think, are nvective, with vertical winds vigorously carrying materials th up and down. Life probably cannot be imagined on eir surfaces because of the high temperatures. The cloud nvironments are perfectly clement, but convection will rry hypothetical cloud organisms down to the depth and y them there. There are two obvious solutions. There ight be small organisms that reproduce as fast as they are rried down to the planetary skillet or the organisms might buoyant. Fish on Earth have float bladders for a similar rpose, and both on Venus and on the Jovian planets, ganisms that are essentially hydrogen-filled balloons can envisioned. For them to float at modest temperatures on enus, they need to be at least a few centimetres across, but r the same purpose on Jupiter, they must be at least metres ross – the size of ping-pong balls and meteorological lloons, respectively. We do not know that such beasts ist, but it is of some little interest to see that they can be nvisioned without doing violence to what is known of ysics, chemistry or biology.

Our profound ignorance of whether other planets harbour e may end within this century. Plans are now afoot for the emical and biological examination of many of these ndidate worlds. The first step was the American Viking issions, which landed two sophisticated automatic labora-ries on Mars in the summer of 1976, almost three hundred ars to the month of Leeuwenhoek's discovery of hay fusoria. Viking found no curious structures nearby (or untering by) which were top-heavy, and no detectable

organic molecules. Of three experiments in microbia metabolism, two in both landing sites repeatedly gave wha seemed to be positive results. The implications are still unde vigorous debate. In addition, we must remember that th two Viking landers examined closely, even with photo graphy, less than one millionth of the surface area of th planet. More observations – particularly with more sophisti cated instrumentation (including microscopes) and wit roving vehicles – are needed. But despite the ambiguou nature of the Viking results, these missions represent th first time in the history of the human species that anothe world has been seriously examined for life.

In the following decades it is likely that there will b buoyant probes into the atmospheres of Venus, Jupiter an Saturn, and landers on Titan, as well as more detaile studies of the surface of Mars. A new age of planetar exploration and exobiology dawned in the seventh decade o the twentieth century. We live in a time of adventure an high intellectual excitement; but also – as the step fro Leeuwenhoek to Pasteur shows – in the midst of a endeavour which promises great practical benefits.

CHAPTER 13

TITAN, THE ENIGMATIC MOON OF SATURN

* * *

On Titan, warmed by a hydrogen blanket,
ice-ribbed volcanoes jet ammonia
dredged out of a glacial heart. Liquid
and frozen assets uphold an empire
bigger than Mercury, and even a little
ce primitive Earth: asphalt plains and hot mineral ponds. But
ow I'd like to take the waters of Titan, under that fume-ridden sky,
where the land's blurred by cherry mist
and high above, like floating wombs,
clouds
tower and swarm, raining down primeval
bisque, while life waits in the wings.

DIANE ACKERMAN,
The Planets (New York, Morrow, 1976)

AN IS NOT a household word, or world. We do not usually nk of it when we run through a list of familiar objects in solar system. But in the last few years this satellite of urn has emerged as a place of extraordinary interest and me significance for future exploration. Our most recent dies of Titan have revealed that it has an atmosphere re like the Earth's – at least in terms of density – than other object in the solar system. This fact alone gives it w significance as the exploration of other worlds begins earnest.

Besides being the largest satellite of Saturn, Titan is also, ording to recent work by Joseph Veverka, James Elliot

and others at Cornell University, the largest satellite in th solar system – about 5,800 kilometres (3,600 miles) i diameter. Titan is larger than Mercury and nearly as larg as Mars. And yet there it is in orbit around Saturn.

We might obtain some clues about the nature of Titan b examining the two major worlds in the outer solar syster – Jupiter and Saturn. Both have a general reddish o brownish coloration. That is, the upper layer of clouds tha we see from the earth have this hue primarily. Somethin in the atmosphere and clouds of these planets is strongl absorbing blue and ultraviolet light, so that the light that i reflected back to us is primarily red. The outer solar system in fact, has a number of objects that are remarkably red Although we have no colour photographs of Titan becaus it is 800 million miles away and has an angular size smalle than the Galilean satellites of Jupiter, photoelectric studie reveal that it is, in fact, very red. Astronomers who though about the problem once believed that Titan was red for th same reason that Mars is red: a rusty surface. But then th reason for Titan's red colour would be different from th reason for Jupiter's and Saturn's, because we do not see t a solid surface on those planets.

In 1944 Gerard Kuiper detected spectroscopically a atmosphere of methane around Titan – the first satellit found to have an atmosphere. Since then, the methan observations have been confirmed, and at least moderatel suggestive evidence for the presence of molecular hydroge has been provided by Lawrence Trafton of the Universit of Texas.

Since we know the amount of gas necessary to produce th observed spectral absorption features, and we know from it mass and radius the surface gravity of Titan, we can deduc the minimum atmospheric pressure. We find it is somethin like 10 millibars, about one percent of the Earth's atmos pheric pressure – a pressure that exceeds that of Mars. Tita

s the most Earth-like atmospheric pressure in the solar stem.

Not only the best, but the only visual telescopic observa-ns of Titan have been made by Audouin Dollfus at the udon Observatory in France. These are hand drawings ne at the telescope during moments of atmospheric adiness. From the variable patches that he observed, llfus concluded that things are happening on Titan that not correlate with the satellite's rotation period. (Titan thought always to face Saturn, as our Moon does the rth.) Dollfus guessed that there might be clouds, at least a patchy sort, on Titan.

Our knowledge of Titan has made a number of substantial antum jumps forward in recent years. Astronomers have cessfully obtained the polarization curve of small objects. e idea is that initially unpolarized sunlight falls on Titan, , and is polarized on reflection. The polarization is ected by a device similar in principle to, but more phisticated and sensitive than, 'polaroid' sunglasses. The ount of polarization is measured as Titan goes through a all range of phases – between 'full' Titan and slightly bbous' Titan. The resulting polarization curve, when npared to laboratory polarization curves, gives informa-n on the size and composition of the material responsible r the polarization.

The first polarization observations of Titan, made by eph Veverka, indicated that the sunlight reflected back m Titan is most likely reflected off clouds and not off a id surface. Apparently there is on Titan a surface and a ver atmosphere that we do not see; an opaque cloud ck and an overlying atmosphere, both of which we do see; d an occasional patchy cloud above that. Since Titan pears red, and we view it at the cloud deck, there must, cording to this argument, be red clouds on Titan.

Additional support for this concept comes from the

extremely low amount of ultraviolet light reflected from Titan, as measured by the Orbiting Astronomical Observatory. The only way to keep Titan's ultraviolet brightness small is to have the ultraviolet absorbing stuff high up in the atmosphere. Otherwise Rayleigh scattering by the atmospheric molecules themselves would make Titan bright in the ultraviolet. (Rayleigh scattering is the preferential scattering of blue rather than red light, which is responsible for blue skies on Earth.)

But material that absorbs in the ultraviolet and violet appears red in reflected light. So there are two separate lines of evidence (or three, if we believe the hand drawings) for an extensive cloud cover on Titan. What do we mean by extensive? More than 90 percent of Titan must be cloaked in clouds to match the polarization data. Titan seems to be covered by dense red clouds.

A second astonishing development was inaugurated in 1971 when D. A. Allen of Cambridge University and T. L. Murdock of the University of Minnesota found that the observed infrared emission from Titan at a wavelength of 10 to 14 microns is more than twice what is expected from solar heating. Titan is too small to have a significant internal energy source like Jupiter or Saturn. The only explanation seemed to be the greenhouse effect in which the surface temperature rises until the infrared radiation trickling out just balances the absorbed visible radiation coming in. It is the greenhouse effect that keeps the surface temperature of the Earth above freezing and the temperature of Venus at 480°C.

But what could cause a Titanian greenhouse effect? It is unlikely to be carbon dioxide and water vapour as on Earth and Venus, because these gases should be largely frozen out on Titan. I have calculated that a few hundred millibars of hydrogen (1,000 millibars is the total sea-level atmospheric pressure on Earth) would provide an adequate

enhouse effect. Since this is more than the amount of trogen observed, the clouds would have to be opaque at tain short wavelengths and more nearly transparent at ain longer wavelengths. James Pollack, at NASA's Ames earch Centre, has calculated that a few hundred millibars nethane might also be adequate and, moreover, might lain some of the details of the infrared emission spectrum Titan. This large amount of methane would also have nide under the clouds. Both greenhouse models have the ue of invoking only gases thought to exist on Titan; of rse, both gases might play a role.

An alternative model of the Titan atmosphere was posed by the late Robert Danielson and his colleagues Princeton University. They suggest that small quantities simple hydrocarbons – such as ethane, ethylene and tylene – which have been observed in the upper atmos- re of Titan absorb ultraviolet light from the Sun and heat upper atmosphere. It is then the hot upper atmosphere l not the surface that we see in the infrared. On this del there need be no enigmatically warm surface, no enhouse effect, and no atmospheric pressure of hundreds nillibars.

Which view is correct? At the present time no one knows. e situation is reminiscent of studies of Venus in the early 0s when the planet's radio-brightness temperature was own to be high, but whether the emission was from a hot face or a hot region of the atmosphere was (appro- ately) hotly debated. Since radio waves pass through all the densest atmospheres and clouds, the Titan problem ght be resolved if we had a reliable measure of the radio- ghtness temperature of the satellite. The first such asurement was performed by Frank Briggs of Cornell h the giant interferometer of the National Radio ronomy Observatory in Green Bank, West Virginia. ggs finds a surface temperature of Titan of −140°C with

an uncertainty of 45°. The temperature in the absence of greenhouse effect is expected to be about −185°C. Briggs' observations therefore seem to suggest a fairly sizable green house effect and a dense atmosphere, but the probable erro of the measurements is still so large as to permit the zer greenhouse case.

Subsequent observations by two other radio astronomica groups give values both higher and lower than Briggs' results. The higher range of temperatures, astonishingly even approaches temperatures in cold regions of the Earth The observational situation, like the atmosphere of Titan seems very murky. The problem could be resolved if w could measure the size of the solid surface of Titan by rada (optical measurements give us the distance from cloudtop t cloudtop). The problem may have to await studies by th Voyager mission, which is scheduled to send two sophisti cated spacecraft by Titan – one very close to it – in 1981.

Whichever model we select is consistent with the re clouds. But what are they made of? If we take an atmospher of methane and hydrogen and supply energy to it, we wil make a range of organic compounds, both simple hydro carbons (like the sort that are needed to make Danielson' inversion layer in the upper atmosphere) and complex ones In our laboratory at Cornell, Bishun Khare and I hav simulated the kinds of atmospheres that exist in the oute solar system. The complex organic molecules we synthesiz in them have optical properties similar to those of th Titanian clouds. We think there is strong evidence fo abundant organic compounds on Titan, both simple gases i the atmosphere and more complex organics in the cloud and on the surface.

One problem with an extensive Titanian atmosphere i that the light gas hydrogen should be gushing away becaus of the low gravity. The only way that I can explain thi situation is that the hydrogen is in a 'steady state'. That is

capes but is replenished from some internal source – anoes, most likely. The density of Titan is so low that its rior must be almost entirely composed of ices. We can k of it as a giant comet made of methane, ammonia water ices. There must also be a small admixture of oactive elements which, while decaying, will heat their oundings. The heat conduction problem has been ked out by John Lewis, of MIT, and it is clear that the r-surface interior of Titan will be slushy. Methane, nonia and water vapour should be outgassed from the rior and broken down by ultraviolet sunlight, producing ospheric hydrogen and cloud organic compounds at the e time. There may be surface volcanoes made of ice ead of rock, spewing out in occasional eruptions not id rock but liquid ice – a lava of running methane, nonia and perhaps water.

There is another consequence of the escape of all this rogen. An atmospheric molecule that achieves escape city from Titan generally does not have escape velocity n Saturn. Thus, as Thomas McDonough and the late l Brice of Cornell have pointed out, the hydrogen that eing lost from Titan will form a diffuse toroid, or ghnut, of hydrogen gas around Saturn. This is a very resting prediction, first made for Titan but possibly vant for other satellites as well. Pioneer 10 has detected h a hydrogen toroid around Jupiter in the vicinity of Io. Pioneer 11 and Voyager 1 and 2 fly near Titan, they y be able to detect the Titan toroid.

Titan will be the easiest object to explore in the outer ar system. Nearly atmosphereless worlds such as Io or the eroids present a landing problem because we cannot use ospheric braking. Giant worlds such as Jupiter and urn have the opposite problem: the acceleration due to vity is so large and the increase in atmospheric density o rapid that it is difficult to devise an atmospheric probe

that will not burn up on entry. Titan, however, has a dens enough atmosphere and a low enough gravity. If it were little closer, we probably would be launching entry probe there today.

Titan is a lovely, baffling and instructive world which w suddenly realize is accessible for exploration: by fly-bys t determine the gross global parameters and to search fo breaks in the clouds; by entry probes to sample the re clouds and unknown atmosphere; and by landers to examin a surface like none we know. Titan provides a remarkabl opportunity to study the kinds of organic chemistry that o Earth may have led to the origin of life. Despite the lo temperatures, it is by no means impossible that there is Titanian biology. The geology of the surface may be uniqu in all the solar system. Titan is waiting ...

CHAPTER 14

THE CLIMATES OF PLANETS

* * *

Is it not the height of silent humour
To cause an unknown change
in the earth's climate?

ROBERT GRAVES,
The Meeting

TWEEN 30 and 10 million years ago, it is thought, tempera-es on Earth slowly declined, by just a few Centigrade grees. But many plants and animals have their life cycles sitively attuned to the temperature, and vast forests eded towards more tropical latitudes. The retreat of the ests slowly removed the habitats of small furry binocular atures, weighing only a few pounds, which had lived out ir days brachiating from branch to branch. With the ests gone, only those furry creatures able to survive on grassy savannas were to be found. Some tens of millions years later, those creatures left two groups of descendants: e which includes the baboons and the other called mans. We may owe our very existence to climatic changes t on the average amount to only a few degrees. Such anges have brought some species into being and ex-guished others. The character of life on our planet has en powerfully influenced by such variations, and it is coming increasingly clear that the climate is continuing change today.

There are many indications of past climatic changes. Some thods reach far into the past, others have only a limited

applicability. The reliability of the methods also differ. On approach, which may be valid for a million years back time, is based on the ratio of the isotopes oxygen 18 oxygen 16 in the carbonates of shells of fossil foraminifer These shells, belonging to species very similar to some th can be studied today, vary the oxygen 16/oxygen 18 rat according to the temperature of the water in which the grew. Somewhat similar to the oxygen-isotope method is on based upon the ration of the isotopes sulphur 34 to sulph 32. There are other, more direct fossil indicators; fo example, the widespread presence of corals, figs and palm denotes high temperatures, and the abundant remains large hairy beasts, such as mammoths, indicate cold temper tures. The geological record is replete with extensive eviden of glaciation – great moving sheets of ice that leave chara teristic boulders and erosional traces. There is also clea geological evidence for beds of evaporites – regions whe briny water has evaporated leaving behind the salts. Suc evaporation occurs preferentially in warm climates.

When this range of climatic information is put togethe a complex pattern of temperature variation emerges. At n time, for example, is the average temperature of the Ear below the freezing point of water, and at no time does even approach the normal boiling point of water. Bu variations of several degrees are common, and eve variations of twenty or thirty degrees may have occurred least locally. Fluctuations of a few degrees Centigrad happen over characteristic times of tens of thousands years, and the recent succession of glacial and interglaci periods has this timing and temperature amplitude. Bu there are climatic fluctuations over much longer periods, th longest being on the order of a few hundred million year Warm periods appear to have occurred about 650 millio years ago and 270 million years ago. By the standards of pa climatic fluctuations, we are now in the midst of an ice ag

most of the Earth's history, there were no 'permanent' aps, as in the Arctic and Antarctic today. We have, over past few hundred years, made a partial emergence from ice age caused by some as yet unexplained minor atic variation; and there are certain signs that we may ge back into the global cold temperatures characteristic ur epoch as seen from the perspective of the immense s of geological time. It is a sobering fact that 2 million s ago the site of the city of Chicago was buried under a of ice.

hat determines the temperature of Earth? As seen from e, it is a rotating blue ball streaked with varying cloud hes, reddish-brown deserts and brilliant white polar . The energy for heating the Earth comes almost usively from sunlight, the energy conducted up from the interior of the Earth amounting to less than one sandth of one percent of that arriving in the form of le light from the Sun. But not all the sunlight is absorbed he Earth. Some is reflected back to space by polar ice, ds, and the rocks and water on the surface of the h. The average reflectivity, or albedo, of the Earth, as sured directly from satellites and indirectly from Earth-e reflected off the dark side of the Moon, is about 35 ent. The 65 percent of sunlight that is absorbed by the th heats it to a temperature which can readily be ulated. This temperature is about −18°C, below the zing point of seawater and some 30°C colder than the sured average temperature of the Earth.

he discrepancy is due to the fact that this calculation ects the so-called greenhouse effect. Visible light from Sun enters the Earth's clear atmosphere and is trans-ed through to the surface. The surface, however, in mpting to radiate back into space, is constrained by the s of physics to do so in the infrared. The atmosphere is so transparent in the infrared, and at some wavelengths

of infrared radiation – such as 6.2 microns or 15 micron radiation would travel only a few centimetres before bei absorbed by atmospheric gases. Since the Earth's atm sphere is murky and absorbing at many wavelengths in t infrared, the thermal radiation given off by the surface the Earth is impeded in escaping to space. In order to ha a close equality between the radiation received by the Ear from the Sun and the radiation emitted by the Earth space, the surface temperature of the Earth must then ri The greenhouse effect is due not to the major atmosphe constituents of the Earth, such as oxygen and nitrogen, b almost exclusively to the minor constituents, especia carbon dioxide and water vapour.

As we have seen, the planet Venus is probably a case whe the massive injection of carbon dioxide and smaller amoun of water vapour into a planetary atmosphere has led such a large greenhouse effect that water cannot be mai tained on the surface in the liquid state; hence, t planetary temperature runs away to some extremely hi value – in the case of Venus, 480°C.

We have so far been talking about average temperatur The temperature of the Earth varies from place to place. is colder at the poles than at the equator because, in gener sunlight falls directly on the equator and obliquely on t poles. The tendency for the temperatures to be very differe between equator and poles on Earth is moderated atmospheric circulation. Hot air rises at the equator a moves at high altitudes to the poles, where it settles a returns to the surface; it then retraces its path, but at lo altitudes, from pole back to equator. This general motion complicated by the rotation of the Earth, its topograp and the phase changes of water – is responsible f weather.

The observed average temperature of about 15°C on t Earth today can be explained quite well by the observ

ity of sunlight, global albedo, the tilt of the rotational
nd the greenhouse effect. But all of these parameters
n principle, vary; and past or future climatic change
e attributed to changes in any of them. In fact, there
been almost a hundred different theories of climatic
e on Earth, and even today the subject is hardly
ed by unanimity of opinion. This is not because
tologists are by nature ignorant or contentious, but
because the subject is exceedingly complex.

th negative and positive feedback mechanisms prob-
xist. Suppose, for example, there were a decrease of a
egrees in the Earth's temperature. The amount of water
ur in the atmosphere is determined almost entirely by
erature and declines by snowing out as the temperature
es. Less water in the atmosphere implies a smaller
house effect and a further lowering of the temperature,
t may result in even less atmospheric water vapour, and
. Likewise, a decline in temperature may increase the
nt of polar ice, increasing the albedo of the Earth and
asing the temperature still further. On the other hand, a
e in temperature may decrease the amount of cloudi-
which will decrease the average albedo of the Earth and
se the temperature – perhaps enough to undo the initial
erature decrease. And it has been proposed recently
the biology of the planet Earth acts as a kind of
ostat to prevent too extreme excursions in temperature
n might have deleterious global biological conse-
es. For example, a decline in temperature may cause
crease of a species of hardy plants that has extensive
d cover and low albedo.

ree of the more fashionable and more interesting
ies of climatic change should be mentioned. The first
ves a change in celestial mechanical variables: the shape
e Earth's orbit, the tilt of its axis of rotation, and the
ssion of that axis all vary over long periods of time

because of the interaction of the Earth with other near celestial objects. Detailed calculations of the extent of su variations show that they can be responsible for at leas few degrees of temperature variation, and with the po sibility of positive feedbacks this might, by itself, adequate to explain major climatic variations.

A second class of theories involves albedo variations. O of the more striking causes for such variations is the injecti into the Earth's atmosphere of massive amounts of dus for example, from a volcanic explosion such as Krakato in 1883. While there has been some debate on whether su dust heats or cools the Earth, the bulk of present calculatio shows that the fine particulates, very slowly falling out Earth's stratosphere, increase the Earth's albedo and ther fore cool it. There is recent sedimentological evidence th past epochs of extensive production of volcanic particulat correspond in time to past epochs of glaciation and lo temperatures. In addition, episodes of mountain buildi and the creation of land surface on the Earth increase t global albedo because the land is brighter than the wate

Finally, there is the possibility of variations in the brigh ness of the Sun. We know – from theories of solar evoluti – that over many billions of years the Sun has been getti steadily brighter. This immediately poses a problem for t most ancient climatology of the Earth, because the S should have been 30 or 40 percent dimmer some 3 or billion years ago; and this is enough, even with the gree house effect, to have resulted in global temperatures w below the freezing point of seawater. Yet there is extensi geological evidence – for example, underwater ripple mark pillow lavas produced by the quenching of magma in t ocean, and fossil stromatolites produced by oceanic algae that there was ample water then available. One propos way out of this quandary is the possibility that there we additional greenhouse gases in the early atmosphere of t

h – especially ammonia – which produced the required perature increment. But apart from this very slow ution of the brightness of the Sun, is it possible that ter-term fluctuations occur? This is an important and lved problem, but recent difficulties in finding neutrinos ich should, according to current theories, be emitted the interior of the Sun – have led to the suggestion the Sun is today in an anomalously dim period.

he inability to distinguish between the various alterna- models of climatic change might appear to be nothing e than an unusually annoying intellectual problem – pt for the fact that there appear to be certain practical immediate consequences of climatic change. Some ence on the trend of global temperature seems to show a slow increase from the beginning of the industrial lution to about 1940, and an alarmingly steep decline in al temperature thereafter. This pattern has been attri- d to the burning of fossil fuels, which has two conse- ces – the liberation of carbon dioxide, a greenhouse gas, the atmosphere, and the simultaneous injection into the osphere of fine particles, from the incomplete burning he fuel. The carbon dioxide heats the Earth; the fine icles, through their higher albedo, cool it. It may be until 1940 the greenhouse effect was winning, and since the increased albedo is winning.

he ominous possibility that human activities may cause lvertent climate modification makes the interest in etary climatology rather important. There are worri- e positive feedback possibilities on a planet with ining temperatures. For example, an increased burning ossil fuels in a short-term attempt to stay warm can lt in more rapid long-term cooling. We live on a planet hich agricultural technology is responsible for the food nore than a billion people. The crops have not been l for hardiness against climatic variations. Human

beings can no longer undertake great migrations in response to climatic change, or at least it is more difficult on a planet controlled by nation-states. It is becoming imperative to understand the causes of climatic variations and to develop the possibility of performing climatic re-engineering of the Earth.

Oddly enough, some of the most interesting hints on the nature of such climatic changes appear to be coming from studies not of the Earth at all, but of Mars. Mariner 9 was injected into Martian orbit on November 14, 1971. It had a useful scientific lifetime of a full terrestrial year and procured 7,200 photographs, covering the planet from pole to pole, as well as tens of thousands of spectra and other scientific information. As we saw earlier, when Mariner 9 arrived at Mars there was virtually no detail whatever to be seen on the surface because the planet was in the throes of a great global dust storm. It was readily observed that the atmospheric temperatures increased, but the surface temperatures decreased during the dust storm, and this simple observation immediately provides at least one clear case of the cooling of the planet by the massive injection of dust into its atmosphere. Calculations have been performed that use precisely the same physics for both the Earth and Mars and treat them as two different examples of the general problem of the climatic effects of massive dust injection into a planetary atmosphere.

There was another and entirely unexpected climatological finding by Mariner 9 – the discovery of numerous sinuous channels, replete with tributaries, covering the equatorial and mid-latitudes of Mars. In all cases where relevant data exist, the channels are going in the proper direction – downhill. Some of them show braided patterns, sand bars, slumping of the banks, streamlined teardrop-shaped interior 'islands' and other characteristic morphological signs of terrestrial river valleys.

ut there is a great problem with the interpretation of the
:tian channels as dry riverbeds, or arroyos: liquid water
arently cannot exist on Mars today. The pressures are
ply too low. Carbon dioxide on Earth is known as both
lid and a gas, but never as a liquid (except in high-
sure storage tanks). In the same way, water on Mars can
: as a solid (ice or snow) or as vapour, but not as a
id. For this reason some geologists are reluctant to
pt the theory that at one time the channels contained
id water. Yet they are dead ringers for terrestrial rivers,
at least many of them have forms inconsistent with
:r possible structures such as collapsed lava tubes, which
: be responsible for sinuous valleys on the Moon.
urthermore, there is an apparent concentration of such
nnels towards the Martian equator. The one striking fact
ut the equatorial regions of Mars is that they are the
places on the planet where the average daytime
perature is above the freezing point of water. And no
:r liquid is simultaneously cosmically abundant, of low
osity, and with a freezing point below Martian
atorial temperatures.
:, then, the channels were made by running water on
:s, that water apparently must have run at a time when
Martian environment was significantly different from
:t it is today. Today Mars has a thin atmosphere, low
peratures and no liquid water. At some time in the past,
ay have had higher pressures, perhaps somewhat higher
peratures and extensive running water. Such an environ-
it appears to be more hospitable to forms of life based
familiar terrestrial biochemical principles than the
:ent Martian environment.
. detailed study of the possible causes of such major
iatic changes on Mars has laid stress on a feedback
:hanism known as advective instability. The Martian
osphere is composed primarily of carbon dioxide. There

seem to be large respositories of frozen CO_2 in at least one of the two polar caps. The pressure of CO_2 in the Martian atmosphere is quite close to the pressure of CO_2 expected in equilibrium with frozen carbon dioxide at the temperature of the cold Martian pole. This is a situation quite similar to the pressure in a laboratory vacuum system determined by the temperature of a 'cold finger' in the system. At the present time the Martian atmosphere is so thin that hot air, rising from the equator and settling at the poles, plays a very small role in heating the high latitudes. But let us imagine that the temperature in the polar regions is somehow slightly increased. The total atmospheric pressure increases, the efficiency of heat transport by advection from equator to pole also increases, polar temperatures increase still further, and we see the possibility of a runaway to high temperatures. Likewise a decrease in temperature, from whatever cause, could bring about a runaway towards a lower temperature. The physics of this Martian situation is easier to work out than the comparable case on Earth, because on Earth the major atmospheric constituents, oxygen and nitrogen, are not condensable at the poles.

For a major increase in pressure to occur on Mars, the amount of heat absorbed in the polar regions of the planet must be increased by some 15 or 20 percent for a period of at least a century. Three possible sources of variation in the heating of the cap have been identified, and they are, interestingly enough, very similar to the three fashionable models of terrestrial climatic change discussed above. In the first, variations of the tilt of the Martian rotational axis towards the Sun are invoked. Such variations are much more striking than for the Earth, because Mars is close to Jupiter, the most massive planet in the solar system, and the gravitational perturbations by Jupiter are pronounced. Here variations in global pressure and temperature will occur on hundred thousand to million year time scales.

Secondly, a variation in the albedo of the polar regions n cause major climatic variations. We can already see bstantial sand and dust storms on Mars, because of which e polar caps seasonally darken and brighten. There has en one suggestion that the climate of Mars may be made ore hospitable if a hardy species of polar plant can be veloped that will lower the albedo of the Martian polar gions.

Finally, there is the possibility of variations in the minosity of the Sun. Some of the channels on Mars have occasional impact crater in them, and crude dating of e channels from the frequency of impacts from inter-anetary space shows that some of them must be about a llion years old. This is reminiscent of the last epoch of gh global temperatures on the planet Earth and raises the ptivating possibility of synchronous major variations in mate between the Earth and Mars.

The subsequent Viking missions to Mars have increased r knowledge about the channels in a major way, have ovided quite independent evidence for a dense earlier mosphere and have demonstrated a great repository of ozen carbon dioxide in the polar ice. When the Viking sults are fully assimilated, they promise to add greatly to r knowledge of the present environment as well as the past story of the planet, and of the comparison between the mates of the Earth and Mars.

When scientists are faced with extremely difficult eoretical problems, there is always the possibility of rforming experiments. In studies of the climate of an entire anet, however, experiments are expensive and difficult to rform, and have potentially awkward social conse-ences. By the greatest good fortune, nature has come to r aid by providing us with nearby planets with signifi-ntly different climates and significantly different physical riables. Perhaps the sharpest test of theories of climat-

ology is that they be able to explain the climates of all the nearby planets, Earth, Mars and Venus. Insights gained from the study of one planet will inevitably aid the study of the others. Comparative planetary climatology appears to be a discipline, just in the process of birth, with major intellectual interest and practical applications.

CHAPTER 15

KALLIOPE AND THE KAABA

* * *

magine them
flitting
cheek to jowl,
these driftrocks
of cosmic ash
sandfold afloat
between Jupiter and Mars.
ga,
Fanny,
Adelheid
Lacrimosa.
es to conjure with,
Dakotan black hills,
a light-opera
staged on a barrier reef.
swarm they may have,
crumbly as blue-cheese,
that ur-moment
when the solar system
e wind.
But now
lumber
so wide apart
each
to its neighbour's
rick-glow
slant millions
and millions
of watertight miles.
Only in the longest view
ey graze
like one herd
on a breathless tundra.

DIANE ACKERMAN,
The Planets (New York, Morrow, 1976)

ONE OF THE seven wonders of the ancient world was t
Temple of Diana at Ephesus, in Asia Minor, an exquisi
example of Greek monumental architecture. The Holy
Holies in this temple was a great black rock, probab
metallic, that had fallen from the skies, a sign from the god
perhaps an arrowhead shot from the crescent moon, t
symbol of Diana the Huntress.

Not many centuries later – perhaps even at the same tim
– another great black rock, according to the belief of man
fell out of the sky on to the Arabian Peninsula. There,
pre-Islamic times, it was emplaced in a Meccan temple, t
Kaaba, and offered something akin to worship. Then, in t
seventh and eighth centuries A.D., came the stunning succe
of Islam, founded by Muhammed, who lived out most of h
days not far from this large dark stone, the presence of whi
might conceivably have influenced his choice of career. T
earlier worship of the stone was incorporated into Islam
and today a principal focus of every pilgrimage to Mec
is that same stone – often called the Kaaba after the temp
that enshrines it. (All religions have shamelessly co-opte
their predecessors – e.g., consider the Christian festival
Easter, where the ancient fertility rites of the spring equin
are today cunningly disguised as eggs and baby anima
Indeed the very name Easter is, according to some et
mologies, a corruption of the name of the great Near Easte
Earth mother goddess, Astarte. The Diana of Ephesus is
later and Hellenized version of Astarte and Cybelle.)

In primitive times, a great boulder falling out of a cle
blue sky must have provided onlookers with a memorab
experience. But it had a greater importance: at the dawn
metallurgy, iron from the skies was, in many parts of t
world, the purest available form of this metal. The milita
significance of iron swords and the agricultural significan
of iron ploughshares made metal from the sky a concern
practical men.

›cks still fall from the skies; farmers still occasionally
t their ploughs on them; museums still pay a bounty for
; and, very rarely, one falls through the eaves of a house,
›wly missing a family in its evening hypnogogic ritual
e the television set. We call these objects meteorites.
ıaming them is not the same as understanding them.
:e, in fact, do meteorites come from?

tween the orbits of Mars and Jupiter are thousands of
ılarly shaped, tumbling little worlds called asteroids or
:toids. 'Asteroid' is not a good term for them because
are not like stars. 'Planetoid' is much better because
are like planets, only smaller, but 'asteroid' is the more
ly used term by far. Ceres, the first asteroid to be
d, was discovered* telescopically on January 1, 1801 –
uspicious finding on the first day of the nineteenth
.ıry – by G. Piazzi, an Italian monk. Ceres is about
) kilometres in diameter and is by far the largest
oid.(By comparison, the diameter of the Moon is 3,464
ıetres.) Since then, more than two thousand asteroids
been discovered. Asteroids are given a number in-
ing their order of discovery. But following Piazzi's lead,
at effort was also made to give them names – female
:s, preferably from Greek mythology. However, two
sand asteroids is a great many, and the nomenclature
mes a little ragged towards the end. We find 1 Ceres,
las, 3 Juno, 4 Vesta, 16 Psyche, 22 Kalliope, 34 Circe,

ıexpected discoveries are useful for calibrating pre-existing ideas.
F. Hegel has had a very powerful imprint on professional philosophy
nineteenth and early twentieth centuries and a profound influence
future of the world because Karl Marx took him very seriously
ugh sympathetic critics have argued that Marx's arguments would
›een more compelling had he never heard of Hegel). In 1799 or 1800
confidently stated, using presumably the full armamentarium of
ophy available to him, that no new celestial objects could exist
the solar system. One year later, the asteroid Ceres was discovered.
then seems to have returned to pursuits less amenable to disproof.

55 Pandora, 80 Sappho, 232 Russua, 324 Bamberga, 4
Eros, 710 Gertrud, 739 Mandevill, 747 Winchester, 9
Rockefelleria, 916 America, 1121 Natasha, 1224 Fantasi
1279 Uganda, 1556 Icarus, 1620 Geographos, 1685 Tor
and 694 Ekard (Drake [University] spelled backwards
1984 Orwell is, unfortunately, a lost opportunity.

Many asteroids have orbits that are highly elliptical
stretched-out, not at all like the almost perfectly circul
orbits of Earth or Venus. Some asteroids have their f
points from the Sun beyond the orbit of Saturn; so
have their near points to the Sun close to the orbit
Mercury; some, like 1685 Toro, live out their days betwe
the orbits of Earth and Venus. Since there are so ma
asteroids on very elliptical orbits, collisions are inevitab
over the lifetime of the solar system. Most collisions w
be of the overtaking variety, one asteroid nudging up
another, making a soft splintering crash. Since the asteroi
are so small, their gravity is low and the collision fragmen
will be splayed out into space into slightly different orbi
from those of the parent asteroids. It can be calculated th
such collisions will produce, on occasion, fragments that
accident intercept the Earth, fall through its atmospher
survive the ablation of entry, and land at the feet of a qui
properly astonished itinerant tribesman.

The few meteorites that have been tracked as they ent
the Earth's atmosphere originated back in the main astero
belt, between Mars and Jupiter. Laboratory studies of t
physical properties of some meteorites show them to ha
originated where the temperatures are those of the ma
asteroid belt. The evidence is clear: the meteorites ensconc
in our museums are fragments of asteroids. We have on o
shelves pieces of cosmic objects!

But which meteorites come from which asteroids? Un
the last few years, answering this question was beyond t
powers of planetary scientists. Recently, however, it h

ne possible to perform spectrophotometry of asteroids
sible and near-infrared radiation; to examine the
ization of sunlight reflected off asteroids as the
etry of the asteroid, the Sun and Earth changes; and
amine the middle-infrared emission of the asteroids.
asteroid observations, and comparable studies of
orites and other minerals in the laboratory, have
ded the first fascinating hints on the correlation
en specific asteroids and specific meteorites. More
90 percent of the asteroids studied fall into one of two
osition groups: stony-iron or carbonaceous. Only a
ercent of the meteorites on Earth are carbonaceous,
arbonaceous meteorites are very friable and rapidly
ier to powder under typical terrestrial conditions. They
ibly also fragment more readily upon entry into the
's atmosphere. Since stony-iron meteorites are much
er, they are disproportionately represented in our
um collections of meteorites. The carbonaceous
orites are rich in organic compounds, including amino
(the building blocks of proteins), and may be rep-
tative of the materials from which the solar system was
ed some 4.6 billion years ago.

ong the asteroids which appear to be carbonaceous are
res, 2 Pallas, 19 Fortuna, 324 Bamberga and 654
da. If asteroids that are carbonaceous on the outside
lso carbonaceous on the inside, then most of the
oidal material is carbonaceous. They are generally dark
ts, reflecting only a small percent of the light shining on
. Recent evidence suggests that Phobos and Deimos,
vo moons of Mars, may also be carbonaceous, and are
ps carbonaceous asteroids that have been captured by
ian gravity.

pical asteroids showing properties of stony-iron
orites are 3 Juno, 8 Flora, 12 Victoria, 89 Julia and
Eros. Several asteroids fit into some other category:

4 Vesta resembles a kind of meteorite called a basalt achondrite, while 16 Psyche and 22 Kalliope appear to b largely iron.

The iron asteroids are interesting because geophysicis believe that the parent body of an object greatly enriche in iron must have been molten so as to differentiate, t separate out the iron from the silicates in the initial chaot jumble of the elements in primordial times. On the oth hand, for the organic molecules in carbonaceous meteorit to have survived at all they must never have been raised t temperatures hot enough to melt rock or iron. Thus, di ferent histories are implied for different asteroids.

From the comparison of asteroidal and meteorit properties, from laboratory studies of meteorites an computer projections back in time of asteroidal motions, may one day be possible to reconstruct asteroid historie Today we do not even know whether they represent a plan that was prevented from forming because of the powerfu gravitational perturbations of nearby Jupiter, or wheth they are the remnants of a fully formed planet that someho exploded. Most students of the subject incline to the forme hypothesis because no one can figure out how to blow up planet – which is just as well. Eventually we may be able t piece together the whole story.

There may also be in hand meteorites which do not com from asteroids. Perhaps there are fragments of your comets, or of the moons of Mars, or of the surface o Mercury, or of the satellites of Jupiter, sitting dusty an ignored in some obscure museum. But it is clear that th true picture of the origin of the meteorites is beginning t emerge.

The Holy of Holies in the Temple of Diana at Ephesus ha been destroyed. But the Kaaba has been carefully preserve although there seems never to have been a true scientif examination of it. There are some who believe it to be a dark

ny rather than metallic meteorite. Recently two geologists
/e suggested, on admittedly quite fragmentary evidence,
t it is instead an agate. Some Muslim writers believe that
colour of the Kaaba was originally white, not black, and
.t the present colour is due to its repeated handling. The
cial view of the Keeper of the Black Stone is that it was
ced in its present position by the patriarch Abraham and
from a religious rather than an astronomical heaven –
.hat no conceivable physical test of the object could be a
of Islamic doctrine. It would nevertheless be of great
erest to examine, with the full armoury of modern
oratory techniques, a small fragment of the Kaaba. Its
nposition could be determined with precision. If it is a
teorite, its cosmic-ray-exposure age – the time spent from
gmentation to arrival on Earth – could be established.
d it would be possible to test hypotheses of origin: such
for example, the idea that some 5 million years ago, about
time of the origin of the hominids, the Kaaba was
pped off an asteroid named 22 Kalliope, orbited the Sun
ages of geological time, and then accidentally en-
ntered the Arabian Peninsula 2,500 years ago.

CHAPTER 16

THE GOLDEN AGE OF PLANETARY EXPLORATION

* * *

> The unquiet republic of the maze
> Of Planets, struggling fierce towards heaven's free wilderness.
>
> PERCY BYSSHE SHELLEY,
> *Prometheus Unbound* (1820)

MUCH OF HUMAN HISTORY can, I think, be described a gradual and sometimes painful liberation from provinci ism, the emerging awareness that there is more to the wo than was generally believed by our ancestors. With aweso ethnocentrism, tribes all over the Earth called themsel 'the people' or 'all men', relegating other groups of huma with comparable accomplishments to subhuman status. T high civilization of ancient Greece divided the human co munity into Hellenes and barbarians, the latter named af an uncharitable imitation of the languages of non-Gre ('Bar Bar ...'). That same classical civilization, which in many respects is the antecedent of our own, called its sm inland sea the Mediterranean – which means the middle the Earth. For thousands of years China called itself Middle Kingdom, and the meaning was the same: China w at the centre of the universe and the barbarians lived outer darkness.

Such views or their equivalent are only slowly changi and it is possible to see some of the roots of racism a nationalism in their pervasive early acceptance by virtua all human communities. But we live in an extraordina

, when technological advances and cultural relativism
made such ethnocentrism much more difficult to
ain. The view is emerging that we all share a common
aft in a cosmic ocean, that the Earth is, after all, a small
with limited resources, that our technology has now
ned such powers that we are able to affect profoundly
nvironment of our tiny planet. This deprovincialization
ankind has been aided powerfully, I believe, by space
oration – by exquisite photographs of the Earth taken
a great distance, showing a cloudy, blue, spinning ball
ke a sapphire in the endless velvet of space; but also by
xploration of other worlds, which have revealed both
similarities and their differences to this home of man-
l.

e still talk of 'the' world, as if there were no others, just
e talk about 'the' Sun and 'the' Moon. But there are
y others. Every star in the sky is a sun. The rings of
nus represent millions of previously unsuspected satel-
orbiting Uranus, the seventh planet. And, as space
cles have demonstrated so dramatically in the last
de and a half, there are other worlds – nearby, relatively
ssible, profoundly interesting, and not a one closely
lar to ours. As these planetary differences, and the
winian insight that life elsewhere is likely to be funda-
tally different from life here, become more generally
ived, I believe they will provide a cohesive and unifying
ence on the human family, which inhabits, for a time,
unprepossessing world among an immensity of others.
anetary exploration has many virtues. It permits us to
e insights derived from such Earth-bound sciences as
orology, climatology, geology and biology, to broaden
powers and improve their practical applications here
Earth. It provides cautionary tales on the alternative
of worlds. It is an aperture to future high technologies
rtant for life here on Earth. It provides an outlet for

the traditional human zest for exploration and discover
our passion to find out, which has been to a very lar
degree responsible for our success as a species. And
permits us, for the first time in history, to approach wi
rigour, with a significant chance of finding out the tr
answers, questions on the origins and destinies of worlds, t
beginnings and ends of life, and the possibility of oth
beings who live in the skies – questions as basic to t
human enterprise as thinking is, as natural as breathing.

Interplanetary unmanned spacecraft of the moder
generation extend the human presence to bizarre and exot
landscapes far stranger than any in myth or legend. Pr
pelled to escape velocity near the Earth, they adjust the
trajectories with small rocket motors and tiny puffs of ga
They power themselves with sunlight and with nuclea
energy. Some take only a few days to traverse the lake
space between Earth and Moon; others may take a year
Mars, four years to Saturn, or a decade to traverse t
inland sea between us and distant Uranus. They flo
serenely on pathways predetermined by Newtonian gravit
tion and rocket technology, their bright metal gleamin
awash in the sunlight which fills the spaces between t
worlds. When they arrive at their destinations, some will f
by, garnering a brief glimpse of an alien planet, perha
with a retinue of moons, before continuing on farther in
the depths of space. Others insert themselves into orb
about another world to examine it at close range, perhaps f
years, before some essential component runs down or wea
out. Some spacecraft will make landfall on another worl
decelerating by atmospheric friction or parachute drag
the precision firing of retrorockets before gently setti
down somewhere else. Some landers are stationary, co
demned to examine a single spot on a world awaiti
exploration. Others are self-propelled, slowly wandering
a distant horizon which holds no man knows what. A

others are capable of remotely acquiring rock and soil sample of another world – and returning it to the h.

l these spacecraft have sensors that extend astonishingly ange of human perception. There are devices that can mine the distribution of radioactivity over another et from orbit; that can feel from the surface the faint ole of a distant planetquake deep below; that can obtain -dimensional colour or infrared images of a landscape none ever seen on Earth. These machines are, at least imited degree, intelligent. They can make choices on the s of information they themselves receive. They can mber with great accuracy a detailed set of instructions h, if written out in English, would fill a good-sized . They are obedient and can be reinstructed by radio ages sent to them from human controllers on Earth. they have returned, mostly by radio, a rich and varied est of information on the nature of the solar system nhabit. There have been fly-bys, crash-landers, soft- ers, orbiters, automated roving vehicles, and unmanned ned sample missions from our nearest celestial neigh- , the Moon – as well as, of course, six successful and ic manned expeditions in the Apollo series. There has a fly-by of Mercury; orbiters, entry probes and landers enus; fly-bys, orbiters and landers to Mars; and fly-bys upiter and Saturn. Phobos and Deimos, the two small ns of Mars, have been examined close up, and tanta- g images have been obtained of a few of the moons of ter.

e have caught our first glimpses of the ammonia clouds great storm systems of Jupiter; the cold, salt-covered ace of its moon, Io; the desolate, crater-pocked, ancient broiling Mercurian wasteland; and the wild and eerie scape of our nearest planetary neighbour, Venus, where clouds are composed of an acid rain that falls con-

tinuously but never patters the surface because that hil
landscape, illuminated by sunlight diffusing through th
perpetual cloud layer, is everywhere at 900 F. And Mar
What a puzzle, what a joy, enigma and delight is Mars, wi
ancient river bottoms; immense, sculpted polar terraces;
volcano almost 80,000 feet high; raging windstorms; balm
afternoons; and an apparent initial defeat of our first pionee
ing effort to answer the question of questions – whether th
planet harbours, now or ever, a home-grown form of life

There are on Earth only two spacefaring nations, on
two powers so far able to send machines much beyond th
Earth's atmosphere – the United States and the Sovi
Union. The United States has accomplished the on
manned missions to another body, the only successful Ma
landers and the only expeditions to Mercury, Jupiter an
Saturn. The Soviet Union has pioneered the automate
exploration of the Moon, including the only unmanne
rovers and return sample missions on any celestial object
and the first entry probes and landers on Venus. Since th
end of the Apollo programme, Venus and the Moon hav
become, to a certain degree, Russian turf, and the rest of th
solar system visited only by American space vehicles. Whi
there is a certain degree of scientific cooperation between th
two spacefaring nations, this planetary territoriality ha
come about by default rather than by agreement. There hav
in recent years been a set of very ambitious but unsuccessf
Soviet missions to Mars, and the United States launched
modest but successful set of Venus orbiters and entry probe
in 1978. The solar system is very large and there is much
explore. Even tiny Mars has a surface area comparable
the land area of the Earth. For practical reasons it is muc
easier to organize separate but coordinated missio
launched by two or more nations than cooperative mul
national ventures. In the sixteenth and seventeenth ce
turies, England, France, Spain, Portugal and Holland eac

ized on a grand scale missions of global exploration
iscovery in vigorous competition. But the economic
ligious motives of exploratory competition then do not
to have their counterparts today. And there is every
to think that national competition in the exploration
planets will, at least for the foreseeable future, be
ful.

EAD TIMES for planetary missions are very long. The
, fabrication, testing, integration and launch of a
l planetary mission takes many years. A systematic
amme of planetary exploration requires a continuing
itment. The most celebrated American achievements
Moon and planets – Apollo, Pioneer, Mariner and
g – were initiated in the 1960s. At least until recently,
nited States has made only one major commitment to
ary exploration in the whole of the decade of the 1970s
Voyager missions, launched in the summer of 1977,
ke the first systematic fly-by examination of Jupiter,
n, their twenty-five or so moons and the spectacular
of the latter.
s absence of new starts has produced a real crisis in
ommunity of American scientists and engineers
nsible for the succession of engineering successes
igh scientific discovery that began in 1962 with the
ner 2 fly-by of Venus. There has been an interruption in
ace of exploration. Workers have been laid off and
d to quite different jobs, and there is a real problem in
ding continuity to the next generation of planetary
ration. For example, the earliest likely response to the
icularly successful and historic Viking exploration of
will be a mission that does not even arrive at the Red
t before 1985 – a gap in Martian exploration of almost
ade. And there is not the slightest guarantee that there
be a mission even then. This trend – a little like

dismissing most of the shipwrights, sail weavers and na gators of Spain in the early sixteenth century – shows so slight signs of reversal. Recently approved was Proj Galileo, a middle-1980s mission to perform the first orbi reconnaissance of Jupiter and to drop the first probe in its atmosphere – which may contain organic molecu synthesized in a manner analogous to the chemical eve which on Earth led to the origin of life. But the followi year Congress so reduced the funds available for Galileo th it is, at the present writing, teetering on the brink of disast

In recent years the entire NASA budget has been w below one percent of the federal budget. The funds spent planetary exploration have been less than 15 percent of th Requests by the planetary science community for n missions have been repeatedly rejected – as one senat explained to me, the public has not, despite *Star Wars* a *Star Trek*, written to Congress in support of planeta missions, and scientists do not constitute a powerful lobb And yet, there are a set of missions on the horizon th combine extraordinary scientific opportunity with rema able popular appeal:

Solar Sailing and Comet Rendezvous. In ordinary int planetary missions, spacecraft are obliged to follo trajectories that require a minimum expenditure of energ The rockets burn for short periods of time in the vicin of Earth, and the spacecraft mainly coast for the rest the journey. We have done as well as we have not because enormous booster capability, but because of great skill w severely constrained systems. As a result, we must acce small payloads, long mission times and little choice departure or arrival dates. But just as on Earth we a considering moving from fossil fuels to solar power, so it in space. Sunlight exerts a small but palpable force call radiation pressure. A sail-like structure with a very large ar for its mass can use radiation pressure for propulsion.

oning the sail properly, we can be carried by sunlight inwards towards and outwards away from the Sun. a square sail about half a mile on each side, but thinner the thinnest Mylar, interplanetary missions can be nplished more efficiently than with conventional rocket ılsion. The sail would be launched into Earth orbit by anned Shuttle craft, unfurled and strutted. It would be traordinary sight, easily visible to the naked eye as a t point of light. With a pair of binoculars, detail on a sail could be made out – perhaps even what on teenth-century sailing ships was called the 'device', appropriate graphic symbol, perhaps a representation ıe planet Earth. Attached to the sail would be a tific spacecraft designed for a particular application. e of the first and most exciting applications being ssed is a comet-rendezvous mission, perhaps a rendez- with Halley's comet in 1986. Comets spend most of time in interstellar space and should provide major on the early history of the solar system and the nature e matter between the stars. Solar sailing to Halley's t might not only provide close-up pictures of the or of a comet – about which we now know close to ing – but also, astonishingly, return a piece of a comet to lanet Earth. The practical advantages and the romance lar sailing are both evident in this example, and it is that it represents not just a new mission but a new planetary technology. Because the development of -sailing technology is behind that of ion propulsion, it latter that may propel us on our first missions to omets. Both propulsion mechanisms have their place in e interplanetary travel. But in the long term I believe sailing will make the greater impact. Perhaps by the twenty-first century there will be interplanetary tas competing for the fastest time from Earth to Mars.

ars Rovers. Before the Viking mission, no terrestrial

spacecraft had successfully landed on Mars. There had b
several Soviet failures, including at least one which
quite mysterious and possibly attributable to the hazard
nature of the Martian landscape. Thus, both Viking 1
Viking 2 were, after painstaking efforts, successfully lan
in two of the dullest places we could find on the Mart
surface. The lander stereo cameras showed distant vall
and other inaccessible vistas. The orbital cameras showed
extraordinarily varied and geologically exuberant landsc
which we could not examine close up with the station
Viking lander. Further Martian exploration, both geolog
and biological, cries out for roving vehicles capable
landing in the safe but dull places and wandering hundr
or thousands of kilometres to the exciting places. Suc
rover would be able to wander to its own horizon every
and produce a continuous stream of photographs of
landscapes, new phenomena and very likely major surpr
on Mars. Its importance would be improved still furthe
it operated in tandem with a Mars polar orbiter wh
would geochemically map the planet, or with an unman
Martian aircraft which would photograph the surface fr
very low altitudes.

Titan Lander. Titan is the largest moon of Saturn
the largest satellite in the solar system (see Chaptar 13)
is remarkable for having an atmosphere denser than tha
Mars and is probably covered with a layer of brown
clouds composed of organic molecules. Unlike Jupiter
Saturn, it has a surface on which we can land, and its d
atmosphere is not so hot as to destroy the organic molecu
A Titan entry-probe and lander mission would probably
part of a Saturn orbital mission, which might also inclu
Saturn entry probe.

Venus Orbital Imaging Radar. The Soviet Venera 9
10 missions have returned the first close-up photograph
the surface of Venus. Because of the permanent cloud p

surface features of Venus are not visible through Earth-
and optical telescopes. However, Earth-based radar and
radar system aboard the small Pioneer Venus orbiter
ve now begun to map Venus surface features, and have
ealed mountains and craters and volcanoes as well as
anger morphology. A proposed Venus orbital imaging
lar would provide pole-to-pole radar pictures of Venus
h much higher detail than can be achieved from the
face of the Earth, and would permit a preliminary
onnaissance of the Venus surface comparable to that
nieved for Mars in 1971–72 by Mariner 9.

Solar Probe. The Sun is the nearest star, the only one
are likely to be able to examine close up, at least for many
cades. A near approach to the Sun would be of great
erest, would help in understanding its influence on Earth,
d would also provide vital additional tests of such theories
gravitation as Einstein's General Theory of Relativity. A
ar probe mission is difficult for two reasons: the energy
quired to undo the Earth's (and the probe's) motion
ound the Sun so it can fall into the Sun, and the
olerable heating as the probe approaches the Sun. The
st problem can be solved by launching the spacecraft out
Jupiter and then using Jupiter's gravitation to fling it into
e Sun. Since there are many asteroids interior to Jupiter's
bit, this might possibly be a useful mission for studying
eriods as well. An approach to the second problem, at
st sight remarkable for its naïveté, is to fly into the Sun
night. On Earth, nighttime is of course merely the
erposition of the solid body of the Earth between us and
e Sun. Likewise for a solar probe. There are some asteroids
at come rather close to the Sun. A solar probe would
proach the Sun in the shadow of a Sun-grazing asteroid
eanwhile making observations of the asteroid as well).
ear the point of closest approach of the asteroid to the
n, the probe would emerge from the asteroidal shadow

and plunge, filled with a fluid that resists heating, as deep into the atmosphere of the Sun as it could until it melte and vaporized – atoms from the Earth added to the neare star.

Manned Missions. As a rule of thumb, a manned missio costs from fifty to a hundred times more than a comparab unmanned mission. Thus, for scientific exploration alon unmanned missions, employing machine intelligence, a preferred. However, there may well be reasons other tha scientific for exploring space – social, economic, politica cultural or historical. The manned missions most frequent talked about are space stations orbiting the Earth (ar perhaps devoted to harvesting sunlight and transmitting in microwave beams down to an energy-starved Earth), ar a permanent lunar base. Also being discussed are rath grand schemes for the construction of permanent space citi in Earth orbit, constructed from lunar or asteroid materials. The cost of transporting materials from such lo gravity worlds as the Moon or an asteroid to Earth orb is much less than transporting the same materials from o high-gravity planet. Such space cities might ultimately b self-propagating – new ones constructed by older ones. Th costs of these large manned stations have not yet bee estimated reliably, but it seems likely that all of them – well as a manned mission to Mars – would cost in th $100 billion to $200 billion range. Perhaps such schem will one day be implemented; there is much that is fa reaching and historically significant in them. But those of who have fought for years to organize space ventur costing less than one percent as much may be forgiven f wondering whether the required funds will be allocated, ar whether such expenditures are socially responsible.

However, for substantially less money, an importa expedition that is preparatory for each of these manne ventures could be mustered – an expedition to an Earth

sing carbonaceous asteroid. The asteroids occur mostly veen the orbits of Mars and Jupiter. A small fraction of n have trajectories that carry them across Earth's orbit occasionally within a few million miles of the Earth. ıy asteroids are mainly carbonaceous – with large ıtities of organic materials and chemically bound water. organic matter is thought to have condensed in the earliest stages of the formation of the solar system from rstellar gas and dust, some 4.6 billion years ago, and their y and comparison with cometary samples would be of aordinary scientific interest. I do not think that materials n a carbonaceous asteroid are likely to be criticized in the e way that the Apollo returned lunar samples were – as ıg 'only' rocks. Moreover, a manned landing on such an ect would be an excellent preparation for the eventual oitation of resources in space. And finally, landing on n an object would be fun: because the gravity field is so , it would be possible for an astronaut to do a standing h jump of about ten kilometres. These Earth-crossing ects, which are being discovered at a rapidly increasing e, are called – by a name selected long before manned ceflight – the Apollo objects. They may or may not be the d husks of comets. But whatever their origin, they are great interest. Some of them are the easiest objects in ce for humans to get to, using only the Shuttle tech- ogy, which will be available in another few years.

SORTS of missions I have outlined are well within our ınological capability and require a NASA budget not ch larger than the present one. They combine scientific l public interest, which very often share coincident ectives. Were such a programme carried out, we would e made a preliminary reconnaissance of all the planets l most of the moons from Mercury to Uranus, made a resentative sampling of asteroids and comets, and

discovered the boundaries and contents of our loca swimming hole in space. As the finding of rings aroun Uranus reminds us, major and unexpected discoveries ar waiting for us. Such a programme would also have made th first halting steps in the utilization of the solar system b our species, tapping the resources on other worlds, arrangin for human habitation in space, and ultimately reworking o terraforming the environments of other planets so tha human beings can live there with minimal inconvenience Human beings will have become a multi-planet species.

The transitional character of these few decades is evident Unless we destroy ourselves, it is clear that humanity wil never again be restricted to a single world. Indeed, th ultimate existence of cities in space and the presence o human colonies on other worlds will make it far mor difficult for the human species to self-destruct. It is clea that we have entered, almost without noticing it, a golde age of planetary exploration. As in many comparable case in human history, the opening of horizons through ex ploration is accompanied by an opening of artistic an cultural horizons. I do not imagine that many people i the fifteenth century ever wondered if they were living in th Italian Renaissance. But the hopefulness, the exhilaration the opening of new ways of thought, the technologica developments, the goods from abroad, and the depro vincialization of that age were then apparent to thoughtfu men and women. We have the ability and the means and – very much hope – the will for a comparable endeavou today. For the first time in human history, it is within th power of this generation to extend the human presence t the other worlds of the solar system – with awe for thei wonders, and a thirst for what they have to teach us.

PART IV

THE FUTURE

CHAPTER 17

'WILL YOU WALK A LITTLE FASTER?'

* * *

'Will you walk a little faster?' said a whiting
to a snail,
'There's a porpoise close behind us,
and he's treading on my tail.'

LEWIS CARROLL,
Alice in Wonderland

MUCH OF human history we could travel only as fast as legs would take us – for any sustained journey, only a miles an hour. Great journeys were undertaken, but very ly. For example, 20,000 or 30,000 years ago, human gs crossed the Bering Strait and for the first time red the Americas, gradually working their way down to southernmost tip of South America, in Tierra del Fuego, e Charles Darwin encountered them on the memorable ge of H.M.S. *Beagle*. A concerted and single-minded rt of a dedicated band to walk from the straits between and Alaska to Tierra del Fuego might have succeeded matter of years; in fact, it probably took thousands of s for diffusion of the human population to carry it so south.

he original motivation for travelling fast must have been, he whiting's plaint reminds us, to escape from enemies predators, or else to seek enemies and prey. A few sand years ago a remarkable discovery was made: the e can be domesticated and ridden. The idea is a very liar one, the horse not having been evolved for humans ride. If looked at objectively, it is only a little less than, say, an octopus riding a grouper. But it worked

and – especially after the invention of the wheel and the chariot – horseback or horse-drawn vehicles represented for millennia the most advanced transportation technology available to the human species. One can travel as much as 10 or perhaps even 20 miles an hour with horse technology.

We have emerged from horse technology only very recently – as, for example, our use of the term 'horsepower' to rate automobile engines clearly shows. An engine rated at 375 horsepower has very roughly the pulling capacity of 375 horses. A team of 375 horses would make a very interesting sight. Arrayed in ranks of five horses each, the team would extend for about two tenths of a mile in length and would be astonishingly unwieldy. On many roads the front rank of horse would be out of sight of the driver. And, of course, 375 horses do not travel 375 times as fast as one horse. Even with enormous teams of horses the speed of transportation was only ten or so times faster than when we could depend upon only our legs.

Thus the changes of the last century in transportation technology are striking. We humans have relied on legs for millions of years; horses for thousands; the internal-combustion engine for less than a hundred; and rockets for transportation for a few decades. But these products of human inventive genius have enabled us to travel on the land and on the surface of the waters a hundred times faster than we can walk, in the air a thousand times faster, and in space more than ten thousand times faster.

It used to be that the speed of communication was the same as the speed of transportation. There were a few fast communication methods earlier in our history – for example, signal flags or smoke signals or even one or two attempts at arrays of signal towers with mirrors employed to reflect sunlight or moonlight from one to another. News of the recapture of the Fortress of Győr by Hungarian commandos from the Turks was apparently conveyed to the Hapsburg

mperor Rudolf II through such a device: the 'moonbeam legraph', invented by the English astrologer John Dee, hich apparently consisted of ten relay stations placed at tervals of forty kilometres between Györ and Prague. But ith only a few exceptions, these methods proved im- actical, and communications proceeded no faster than a an or a horse. This is no longer true. Communication by lephone and radio is now at the velocity of light – 186,000 iles per second, or about two-thirds of a billion miles per our. This is not simply the latest advance: it is the last lvance. So far as we know, from Einstein's Special Theory Relativity, the universe is constructed in such a way (at ast around here) that no material object and no informa- on can be transmitted faster than the velocity of light. his is not an engineering barrier like the so-called sound rrier, but a fundamental cosmic speed limit built deeply to the fabric of nature. Still, two-thirds of a billion miles r hour is fast enough for most practical purposes.

What is remarkable is that in communications technology e have already reached this ultimate limit and have adapted it so well. There are few people who emerge breathless d palpitating from a routine long-distance telephone call, tounded at the speed of transmission. We take this almost stantaneous means of communication for granted. Yet transportation technology, while we have not achieved eeds at all approaching the velocity of light, we find rselves colliding with other limits, physiological and chnological:

Our planet turns. When it is midday at one spot on the rth, it is the dead of night on the other side. The Earth s therefore been conveniently arranged into twenty-four ne zones of more or less equal width, making strips of ngitude around the planet. If we fly very fast, we create uations our minds can accommodate but our bodies can ide only with great difficulty. It is a commonplace today

to fly in relatively short trips westward and arrive before w leave – for example when we take less than an hour t fly between two points separated by one time zone. When take a 9 P.M. flight to London, it is already tomorrow a my destination. When I arrive, after a five- or six-hou flight, it is late at night for me but the beginning of th business day at my destination. My body senses somethin wrong, my circadian rhythms go awry, and it takes a fe days to get adjusted to English time. A flight from Ne York to New Delhi is, in this respect, even more vexing.

I find it very interesting that two of the most gifted an inventive science-fiction writers of the twentieth century Isaac Asimov and Ray Bradbury – both refuse to fly. Thei minds have come to grips with interplanetary and interstella spaceflight, but their bodies rebel at a DC-3. The rate o change in transportation technology has simply been to great for many of us to accommodate conveniently.

Much stranger possibilities are now practical. The Eart turns on its axis once every twenty-four hours. The circum ference of the Earth is 25,000 miles. Thus, if we were able t travel at 25,000/24 = 1,040 miles per hour, we could jus compensate for the Earth's rotation, and travelling west ward at sunset, could maintain ourselves at sunset for th entire journey even if we circumnavigated the planet. (I fact, such a journey would also maintain us at the sam *local* time as we journey westward from time zone to tim zone, until we cross the international dateline and plung precipitously into tomorrow.) But 1,040 miles per hour is les than twice the speed of sound and there are, worldwide dozens of kinds of aircraft, chiefly military, that are capabl of such speeds.*

* In manned Earth orbital flights, still other problems arise. Consider religious Muslim or Jew circling the Earth once every ninety minutes. he obligated to celebrate the Sabbath every seventh orbit? Spacefligh provides access to environments very different from those in which w and our customs have grown up.

ome commercial aircraft, such as the Anglo-French ıcorde, have comparable capabilities. The question, I .k, is not: Can we go faster? but Do we have to? There been concern expressed, some of it in my view quite ropriately, about whether the conveniences supersonic sports provide can possibly compensate for their overall and their ecological impact.

lost of the demand for high-speed long-distance travel es from businessmen and government officials who need ıave conferences with their opposite numbers in other es or countries. But what is really involved here is not transportation of material but the transportation of ɔrmation. I think much of the necessity for high-speed ısport could be avoided if the existing communications ınology were better used. I have many times participated overnment or private meetings in which there were, say, nty participants, each of whom was paid $500 for ısportation and living expenses merely to attend the ting – the cost of which was therefore $10,000 just to the participants together. But all the participants ever hange is information. Video phones, leased telephone s, and facsimile reproducers to transmit paper copies notes and diagrams would, I believe, serve as well or n better. There is no significant function of such a ting – including private discussions among the par-pants 'in the corridor' – that cannot be performed less ensively and at least equally conveniently with com-nications rather than transportation technology.

There are certainly advances in transportation that seem ne promising and desirable: vertical takeoff and landing TOL) aircraft are a remarkable boon for isolated and ıote communities in case of medical or other emergencies. the recent advances in transportation technology that I l most appealing are rubber fins for snorkel and scuba ing and hang gliders. These are technological advances

much in the spirit of those sought by Leonardo da Vinci in mankind's first serious technological pursuit of flight in the fifteenth century; they permit an individual human being with little more than his own resources to enter – at a speed that is adequately exhilarating – another medium entirely.

WITH THE DEPLETION of fossil fuels I think it very likely that automobiles powered by internal-combustion engines will be with us for at most a few decades longer. The transportation of the future will simply have to be different. We can imagine quite comfortable and adequately speedy steam, solar, fuel-cell or electric ground vehicles, generating very little pollution and employing a technology comfortably accessible to the user.

Many responsible medical experts are concerned that we in the West – and increasingly even in developing countries – are becoming too sedentary. Driving an automobile exercises very few muscles. The demise of the automobile surely has many positive aspects when viewed in the long run, one of which is a return to the oldest transportation mechanism, walking, and to bicycling, which is in many ways the most remarkable.

I can easily imagine a healthy and stable future society in which walking and bicycling are the primary means of transportation; with pollution-free low-speed ground cars and railed public transportation systems widely available and the most sophisticated transportation devices used relatively rarely by the average person. The one application of transportation technology that requires the most sophisticated technology is spaceflight. The returns in immediate practical benefits, scientific knowledge and appealing exploration provided by unmanned spaceflight are very impressive, and I would expect an increasing rate of space vehicle launches by many nations in the next few decades using more subtle forms of transportation, as described in

revious chapter. Nuclear electric, solar sailing and ion ulsion schemes have been proposed and are to some e under development. As nuclear-fusion power plants developed for Earth-bound applications in a few des, there should be a development of fusion space nes as well.

e gravitational forces of planets have already been to give velocities otherwise unobtainable. Mariner 10 ed Mercury only because it flew so close to Venus Venus' gravity provided a significant boost in speed. Pioneer 10 was boosted into an orbit that will carry t of the solar system entirely, only because of a close ge by the giant planet Jupiter. In a way Pioneer 10 and nd Voyager 1 and 2 are our most advanced trans- tion systems. They are leaving the solar system at a l of roughly 43,000 miles per hour, carrying messages yone who may intercept them out there in the dark of ight sky from the people of the Earth – who, only a little ago, could travel no faster than a few miles per hour.

CHAPTER 18

VIA CHERRY TREE, TO MARS

* * *

O for a Muse of fire, that would ascend
The brightest heaven of invention ...

WILLIAM SHAKESPEARE,
Henry V, Prologue

IT IS A LAZY afternoon in an exquisite New England autumn. In about ten weeks it will be January 1, 1900, and your diary, into which are committed the events and ideas of your young life, will never again bear an entry with a date in the 1800s. You have just turned seventeen. You are looking forward to being a sophomore in high school, but you are now at home, in part because you mother is seriously ill with tuberculosis and in part because of your own chronic stomach pains. You are bright, with a certain flair for the sciences, but no one has ever indicated that you might have an extraordinary talent. You are complacently viewing the New England countryside from the limb of a tall old cherry tree which you have climbed, when suddenly you are struck by an idea, an overpowering and compelling vision that it might be possible, in fact rather than in fancy, to voyage to the planet Mars.

When you descend from the cherry tree you know that you are a very different boy from the one who climbed it. Your life's work is clearly set out for you, and for the next forty-five years your dedication never wavers. You have been smitten by the vision of flight to the planets. You are deeply moved and quietly awed by the vision in the cherry tree.

ıe next year, on the anniversary of that vision, you climb
ɜ tree again to savour the joy and meaning of the
perience; and forever after you make a point in your
ıry of calling the anniversary of that experience 'Anni-
rsary Day' – every October 19 until your death in the
ddle 1940s, by which time your theoretical insights and
actical innovations have solved essentially all techno-
gical impediments to interplanetary flight.

Four years after your death a WAC Corporal mounted on
ɜ nose of a V-2 is successfully fired to an altitude of 250
les, for all practical purposes to the threshold of space.
l essential design elements of the WAC Corporal and the
2, and the very concept of the multiple staging of rockets,
ve been worked out by you. A quarter of a century later,
manned space vehicles will have been launched to all the
inets known to ancient man; a dozen men will have set
ot on the Moon; and two exquisitely miniaturized space-
ıft named Viking will be on their way to Mars to attempt
ɜ first search for life on that planet.

BERT H. GODDARD never questioned or equivocated on the
olve he made in the cherry tree on the farm of his great-
nt Czarina in Worcester, Massachusetts. While there were
hers who had comparable visions – notably Konstantin
luardovich Tsiolkovsky in Russia – Goddard represented
unique combination of visionary dedication and tech-
logical brilliance. He studied physics because he needed
ysics to get to Mars. He was for many years professor
physics and chairman of the physics department at Clark
niversity in his hometown of Worcester.

In reading the notebooks of Robert Goddard, I am struck
how powerful his exploratory and scientific motivations
re, and how influential speculative ideas – even erroneous
es – can be on the shaping of the future. In the few years
rrounding the turn of the century, Goddard's interests

were profoundly influenced by the idea of life on other worlds. He was intrigued by the claims of W. H. Pickering, of the Harvard College Observatory, that the Moon has a perceptible atmosphere, active volcanism, variable frost patches, and even changing dark markings, which Pickering interpreted variously as the growth of vegetation or even as the migration of enormous insects across the floor of the crater Eratosthenes. Goddard was captivated by the science fiction of H. G. Wells and Garrett P. Serviss, particularly the latter's *Edison's Conquest of Mars*, which, Goddard reported, 'gripped my imagination tremendously'. He attended and enjoyed lectures by Percival Lowell, who was an eloquent advocate of the proposition that intelligent beings inhabit the planet Mars. And yet, through all of this, while his imagination was intensely stimulated, Goddard managed to retain a sense of scepticism very rare in young people given to interplanetary epiphanies high up in cherry trees: 'The actual conditions may be entirely different ... from those which Professor Pickering suggests ... The only antidote for fallacies is – in a word – to take nothing for granted.'

On January 2, 1902, we know from Goddard's notebook, he wrote an essay on 'The Habitability of Other Worlds'. The paper had not been found among Goddard's writings, which seemed to me a great pity, since it might have given us a better understanding of the extent to which the search for extraterrestrial life was a prime motive in Goddard's lifework.*

In his early postdoctoral years Goddard successfully

* In a commencement address at Clark University on May 18, 1978, I made some similar remarks. Dorothy Mosakowski in the Rare Book Room at Clark's Goddard Memorial Library then searched for and found this little essay which had been listed as lost. In it we discover that Goddard was attracted to but cautious about the possibility of life on Mars, certain of the existence of extrasolar planetary systems and deduced 'that among

rsued an experimental verification of his ideas on solid-
l liquid-fuelled rocket flight. In this endeavour he was
›ported principally by two men: Charles Greeley Abbott
l George Ellery Hale. Abbott was then a young scientist
the Smithsonian Institution, of which he later became
retary, the quaint designation by which the executive
cer of that organization is still known. Hale was the
ving force behind American observational astronomy at
time; before he died he had founded the Yerkes, Mount
lson and Mount Palomar observatories, each housing, in
time, the largest telescope in the world.

Both Abbott and Hale were solar physicists, and it seems
ar that both had been captured by the young Goddard's
ion of a rocket sailing free above the obscuring blanket
the Earth's atmosphere, able to view the Sun and stars
mpeded. But Goddard soared far beyond this daring
ion. He talked and wrote of experiments on the com-
sition and circulation of the upper atmosphere of the
rth, of performing gamma-ray and ultraviolet observa-
ns of the Sun and stars from above the Earth's atmos-
re. He conceived of a space vehicle passing 1,000 miles
›ve the surface of Mars – by a curious historical accident
t the low point in the orbits of the Mariner 9 and Viking
cecraft. Goddard calculated that a reasonably sized
scope at such a vantage point would be able to photo-
ph features tens of metres across on the surface of the
d Planet, which is the resolution of the Viking orbiter
neras. He conceived of slow interstellar flight at velocities

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se countless planets there are conditions of heat and light equivalent to
se we experience; and if this is the case, and the planet is near our age
l size, there may very likely exist human beings like ourselves, probably
h strange costumes and still stranger manners.' But he also says: 'It is
the distant future to answer if we will ever realize truth from our
mises.'

and time scales just equivalent to that of the Pioneer 10 an 11 spacecraft, our first interstellar emissaries.

Goddard's spirit soared higher still. He conceived, no casually but quite seriously, of solar-powered spacecraf and in a time when any practical application of nuclea energy was publicly ridiculed, nuclear propulsion for spac craft over vast interstellar distances. Goddard imagined time in the far distant future when the Sun has grown col and the solar system become uninhabitable, when manne interstellar spacecraft would be outfitted by our remot descendants, to visit the stars – not merely the nearby star but also remote star clusters in the Milky Way Galaxy. H could not imagine relativistic spaceflight and so hypothe sized a method of suspended animation of the human cre or – even more imaginative – a means of sending th genetic material of human beings which would auto matically, at some very distant time, be allowed to re combine and produce a new generation of people.

'With each expedition,' he wrote, 'there should be take all the knowledge, literature, art (in a condensed form and description of tools, appliances, and processes, in a condensed, light, and indestructible a form as possible, s that the new civilization could begin where the old ended These final speculations, entitled 'The Last Migration', wer sealed in an envelope with instructions to be read 'only by a optimist'. And that he surely was – not a Pollyanna wh chooses to ignore the problems and evils of our times, bu rather, a man committed to the improvement of the huma condition and the creation of a vast prospect for the futu of our species.

Goddard's dedication to Mars was never far from h mind. In the wake of one of his first experimental successe he was induced to write a press release on the details of h launch and its ultimate significance. He wished to discu spacecraft to Mars but was dissuaded on the ground that th

vas too fantastic. As a compromise he talked about sending a quantity of magnesium flash powder which would make a visible bright flare on the Moon when it landed. This caused a sensation in the press. Goddard was for many years after disparagingly referred to as 'the Moon Man', and he remained rueful about his relations with the press ever after. An editorial in the *New York Times* which criticized Goddard for having 'forgotten' that a rocket will not work in the vacuum of space because it has nothing to push against may have contributed to his unease. The *Times* discovered Newton's third law of motion and retracted its error only in the age of Apollo.) Goddard mused: 'From that day, the whole thing was summed up, in the public mind, in the words "moon rocket"; and thus it happened that in trying to minimize the sensational side, I had really made more of a stir than if I had discussed transportation to Mars, which would probably have been considered as ridiculous by the press representative and doubtless never mentioned.'

Goddard's notebooks are not filled with psychological insights. That was not, at least not very much, the spirit of the times in which he lived.* But there is a remark in Goddard's notebooks that can be only a flash of poignant self-insight: 'God pity a one-dream man.' That surely is what Goddard was. He knew great satisfaction in seeing the advances in rocket technology, but it must have been agonizingly slow. There are so many letters from Abbott

* Although, remarkably, he was in Worcester in the year 1909 when Sigmund Freud and Carl Gustav Jung gave the first comprehensive discussion in the English language of those institutionalized insights called psychoanalysis. Many American psychiatrists got their first glimpses of the subject from Freud's Clark University lectures. One wonders if the middle-aged bearded Viennese physician and the young mustachioed American physics graduate student nodded to each other in passing on the Clark University campus, on their way to their separate destinies.

urging faster progress, and so many responses fro
Goddard citing practical impediments. Goddard never liv
to see the beginning of rocket astronomy and high-altitu
meteorology, much less flights to the Moon or planets.

But all these things are happening because of what a
very clearly the technological fruits of Goddard's geniu
October 19, 1976, was the 77th Anniversary Day of t
Martian vision of Robert H. Goddard. On that day the
were two functioning orbiters and two working landers
Mars, the Viking spacecraft whose origins can be traced wi
utter confidence back to a boy in a cherry tree in a Ne
England autumn in 1899. Among its many other objective
Viking had the task of checking out the possibility of li
on Mars, the prospect that was so powerful a motivation f
Goddard so many years before. Curiously, we are still n
sure what the Viking biology results mean. Some think th
microbial life may have been discovered; others think
unlikely. It is clear that a major programme of futu
exploration of Mars will be required to understand ju
where in cosmic evolution this neighbouring world lies a
what its connection is with the state of evolution on o
own planet.

From its earliest stages, rocket technology develop
because of an interest in life on other worlds. And no
that we have landed on Mars, obtained tantalizing a
enigmatic biological results, the follow-on missions – rovi
vehicles and returned sample canisters – in turn requi
further developments in spacecraft technology, a mutu
causality that I think Goddard would have appreciated.

CHAPTER 19

EXPERIMENTS IN SPACE

* * *

We ever long for visions of beauty,
We ever dream of unknown worlds.

MAXIM GORKY

TIL RELATIVELY recently, astronomy suffered from a ious impediment and remarkable peculiarity: it was the y thoroughly nonexperimental science. The materials of dy were all up there, and we and our machines were all wn here.

No other science was so severely constrained. In physics l chemistry, of course, all is forged on the anvil of eriment, and those who doubt a given conclusion are e to perform a wide range of alternative manipulations natter and energy in an attempt to extract contradictions alternative explanations. Evolutionary biologists, even se of very patient temperaments, cannot afford to wait ew million years to observe one species evolve into ther. But experiments on common amino acid sequences, yme structure, nucleic acid codes, chromosomal band-, and anatomy, physiology and behaviour make a com-ling case for the fact that evolution has occurred and arly show which plant or animal groups (such as human ngs) are related to which others (such as the great apes). t is true that geophysicists, studying the deep interior of Earth, cannot travel to the Wiechert discontinuity ween core and mantle, or (just yet) to the Mohorovicic continuity between mantle and crust. But batholiths,

extruded from the deep interior, can be found here and the on the surface and examined. The geophysicists have reli largely on seismic data, and here, like astronomers, th could not force the favours of nature but were compell to await their voluntary bestowal – for example, in seismic event situated on the other side of the Earth so th one of two nearby seismometers would be in the shado of the Earth's core and the other not. But impatie seismologists can and have set off their own chemical a nuclear explosions to ring Earth like a bell. And there a intriguing recent hints that it may be possible to turn eart quakes on and off. Those geologists intolerant of inferent reasoning could always go to the field and examine co temporary erosion processes. But there was no exa astronomical equivalent of the hard-rock geologist.

We have been restricted to the electromagnetic radiati reflected and emitted by astonomical objects. We have n been able to examine pieces of stars or planets* in o laboratories or to fly into such objects to examine them *situ*. Ground-based passive observations have restricted to a narrow fraction of the conceivable data on astronomic objects. Our position has been much worse than that of t fabled six blind men in pursuit of the nature of the elepha It has been more like one blind man in a zoo. We we standing there for centuries stroking a left hind foot. It not surprising that we did not deduce tusks, or notice th the foot did not belong to an elephant at all. If, accident, the orbital plane of the double star was in our li of sight, we would see eclipses; otherwise not. We cou not move to a position in space from which the eclips could be observed. If we were observing a galaxy when supernova was exploding, we could examine the supernov spectrum; otherwise not. We do not have the ability

* With the sole exception of the meteorites (see Chapter 15).

orm experiments on supernova explosions – which is as well. We could not examine in the laboratory the rical, thermal, mineralogical and organic chemical perties of the lunar surface. We were restricted to ences from the visible light reflected and the infrared radio waves emitted by the moon, aided by occasional ral experiments such as eclipses and lunations.

ut all that is gradually changing. Ground-based astrons have, at least for nearby objects, an experimental tool: r astronomy. At our convenience, at our choice of uency, polarization, bandpass and pulse length, we can diate a nearby moon or planet with microwaves and nine the returned signal. We can wait for the object to te underneath the beam and illuminate some other place ts surface. Radar astronomy has delivered a host of new clusions on the rotation periods of Venus and Mercury, related problems in the tidal evolution of the solar em, on the craters of Venus, the fragmented surface of Moon, the elevations of Mars, and the size and compon of the particles in the rings of Saturn. And radar onomy is just beginning. We are still restricted to low udes, and for the outer solar system, to sun-facing ispheres. But with the newly resurfaced Arecibo telepe of the National Astronomy and Ionosphere Center Puerto Rico, we will be able to map the surface of us to a resolution of 1 kilometre – better than the best und-based photographic resolution of the lunar surface – obtain a host of new information on the asteroids, the lean satellites of Jupiter and the rings of Saturn. For the time we are poking around in cosmic stuff, electrognetically fingering the solar system.

much more powerful technique of experimental (as posed to observational) astronomy is spacecraft explora-. We can now travel into the magnetospheres and ospheres of the planets. We can land on and rove over

their surfaces. We can collect material directly from the int
planetary medium. Our first preliminary steps into spa
have shown us a wide range of phenomena we never kn
existed: the Van Allen trapped-particle belts of the earth; t
mass concentrations beneath the circular maria of the moo
the sinuous channels and great volcanoes of Mars; t
cratered surfaces of Phobos and Deimos. But what I a
most struck by is that, before the advent of space vehicl
astronomers did very well – hamstrung though they we
The interpretations of the observations available to th
were remarkably good. Space vehicles are ways of checki
out the conclusions drawn inferentially by astronomers
method of determining whether astronomical deductions
very distant objects – objects so far away as to be entir
inaccessible by space vehicles in the near future – shou
be believed.

ONE OF THE EARLIEST major debates in astronomy was
whether the Earth or the Sun was at the centre of the so
system. The Ptolemaic and Copernican views explain t
apparent motion of the Moon and planets to comparal
precision. For the practical problem of predicting t
positions of the Moon and planets as seen from the surfa
of the Earth, it hardly mattered which hypothesis w
adopted. But the philosophical implications of the ge
centric and heliocentric hypotheses were quite different. A
there were ways of finding out which was right. In t
Copernican view, Venus and Mercury should go throu
phases like the Moon. In the Ptolemaic view, they shou
not. When Galileo, using one of the first astronomi
telescopes, observed a crescent Venus, he knew he h
vindicated the Copernican hypothesis.

But space vehicles provide a more immediate test. Accor
ing to Ptolemy, the planets are affixed to immense crystalli
spheres. But when Mariner 2 or Pioneer 10 penetrated t

es of Ptolemy's supposed crystal spheres, no impedi-
to their motion was detected; and, more directly, the
stic and other micrometeorite detectors heard not even
aintest whisper of tinkling, much less the sound of
hed crystal. There is something very satisfying and
ediate about this sort of test. There are probably no
maists in our midst. But there might be some with
ring doubts about whether Venus could not be made to
rough phases in some modified geocentric hypothesis.
e people can now rest easy.

fore space vehicles, the German astrophysicist Ludwig
nann was intrigued by the observations of the apparent
eration of bright knots in the well-developed tails of
ts passing through the inner solar system. Biermann
ed that the radiation pressure of sunlight was in-
uate to account for the observed acceleration and made
novel suggestion that there were charged particles
ming out from the Sun which, in interaction with the
t, produced the observed acceleration. Well, maybe.
could it not be equally due to, say, chemical explosions
e nucleus of the comet? Or some other explanation? But
irst successful interplanetary spacecraft, Mariner 2, in
ourse of its fly-by of Venus, determined the existence
solar wind with velocities and electron densities in just
ange that Biermann had calculated would be necessary
celerate his knots.

the same period there was a debate on the nature of the
wind. In one view, that of Eugene Parker of the
versity of Chicago, it was caused by hydrodynamical
out from the Sun; in another view, by evaporation
the top of the solar atmosphere. In the hydrodynamic
nation there should be no fractionation by mass; that
e atomic composition of the solar wind should be the
as that of the Sun. But in the evaporation hypothesis,
ighter atoms escape the Sun's gravity more easily, and

heavy elements should be preferentially depleted in the so
wind. Interplanetary spacecraft have found that the ratio
hydrogen to helium in the solar wind is precisely that
the Sun, and have thereby provided convincing support
the hydrodynamic hypothesis of the origin of the solar wi

In these examples from solar wind physics, we find t
the spacecraft experiments provided the means for maki
critical judgments among competing hypotheses. In ret
spect, we find that there were astronomers such as Bi
mann and Parker who were right for the right reaso
But there were others, equally bright, who disbelieved th
and might have gone on disbelieving them had not
critical spacecraft experiments been performed. What
remarkable is not that there were alternative hypothe
which we now see to be incorrect, but rather that on
basis of the very meagre data available *anyone* was sm
enough to divine the correct answer – inferentially, us
intuition, physics and common sense.

Before the Apollo missions, the uppermost layer of
lunar surface could be examined by visible, infrared a
radio observations during both lunations and eclipses, a
the polarization of sunlight reflected off the lunar surf
had been measured. From these observations, Thomas G
of Cornell University prepared a dark powder which,
the laboratory, reproduced the observed properties of
lunar surface very well. This 'Golddust' can even be p
chased for a modest price from the Edmund Scient
Company. A naked-eye comparison of lunar dust return
by Apollo astronauts with Golddust shows them to
almost indistinguishable. In particle-size distribution, and
electrical and thermal properties, they are a very cl
match. However, their chemical compositions are v
different. Golddust is primarily Portland cement, charc
and hairspray. The moon has a less exotic composition.
the observed lunar properties available to Gold bef

llo did not strongly depend on the chemical composition
ıe lunar surface. He was able to deduce very well that
tion of the lunar-surface properties which was relevant
re-1969 observations of the Moon.

rom the study of the available radio and radar data, we
able to deduce the high surface temperature and high
ıce pressures of Venus before the first Soviet Venera
y probe made *in situ* observations on the atmosphere,
subsequent Venera probes on the surface. Likewise, we
ectly deduced the existence of elevation differences on
s as great as 20 kilometres, although we were mistaken
hinking that dark areas were systematically at high
ations on the planet.*

erhaps one of the most interesting such confrontations
tronomical inference with spacecraft observations is the
of the magnetosphere of Jupiter. In 1955 Kenneth
nklin and Bernard Burke were testing a radiotelescope
Washington, D.C., intended for mapping galactic radio
sion at a frequency of 22 Hertz. They noticed a regularly
rring interference on their records, which they at first
ıght was due to some conventional source of radio noise
ch as a faulty ignition system on some nearby tractor.
they soon discovered that the timing of the interference
esponded perfectly well with transits overhead of the
et Jupiter. They had discovered that Jupiter was a
erful source of decametre radio emission.

ubsequently Jupiter was found to be a bright source at
metre wavelengths as well. But the spectrum was very
ıliar. At a wavelength of a few centimetres, very low
peratures of around 140°K were found – temperatures
parable to those uncovered for Jupiter at infrared wave-
ths. But at decimeter wavelengths – up to one metre –
brightness temperature increased very rapidly with

have discussed these successful inferences and their spacecraft con-
tions in Chapters 12, 16 and 17 of *The Cosmic Connection*.

wavelength, approaching 100,000 K. This was too high
temperature for thermal emission – the radio radiation tha
all objects put out, simply because they are at a temperatur
above absolute zero.

Frank Drake, then of the National Radio Astronom
Observatory, proposed in 1959 that this spectrum implie
that Jupiter was a source of synchrotron emission – th
radiation that charged particles emit in their direction o
motion when travelling close to the speed of light: On Earth
synchrotons are convenient devices used in nuclear physic
for accelerating electrons and protons to such hig
velocities, and it is in synchrotons that such emission wa
first generally studied. Synchrotron emission is polarized
and the fact that the decimetre radiation from Jupiter i
also polarized was an additional point in favour of Drake'
hypothesis. Drake suggested that Jupiter was surrounded b
a vast belt of relativistic charged particles similar to th
Van Allen radiation belt around the Earth, which had the
just been discovered. If so, the decimetre emitting regio
should be much larger than the optical size of Jupiter. Bu
conventional radio telescopes have inadequate angula
resolution to make out any spatial detail whatever at th
range of Jupiter. A radio interferometer can achieve suc
resolution, however. In the spring of 1960, very soon afte
the suggestion was made, V. Radhakrishnan and hi
colleagues at the California Institute of Technology em
ployed an interferometer composed of two 90-foot-diamete
antennas mounted on railroad tracks and separable b
almost a third of a mile. They found that the region o
decimetre emission around Jupiter was considerably large
than the ordinary optical disc of Jupiter, confirming Drake'
proposal.

Subsequent higher-resolution radio interferometry ha
shown Jupiter to be flanked by two symmetric 'ears' o
radio-wave emission with the same general configuration a

Van Allen radiation belts of the Earth. The general
ure has evolved that on both planets electrons and
:ons from the solar wind are trapped and accelerated by
planetary magnetic dipole field and are constrained to
al along the planet's lines of magnetic force, bouncing
1 one magnetic pole to the other. The radio-emitting
on around Jupiter is identified with its magnetosphere.
stronger the magnetic field, the farther out from the
et the boundary of the magnetic field will be. In
ition, matching the observed radio spectrum from
chrotron emission theory specifies a magnetic field
ngth. The field strength could not be specified to very
t precision but most estimates from radio astronomy in
late 1960s and early 1970s were in the range of 5 to 30
ss, some ten to sixty times the surface magnetic field of
Earth at the equator.

adhakrishnan and colleagues also found that the
rization of the decimetre waves from Jupiter varied
larly as the planet rotated, as if the Jovian radiation
s were wobbling with respect to the line of sight. They
posed that this was due to a 9-degree tilt between the
of rotation and the magnetic axis of the planet – not
different from the displacement between the north
graphic and the north magnetic poles of Earth. Subse-
nt studies of the decimetre and decametre emission by
es Warwick of the University of Colorado and others
gested that the magnetic axis of Jupiter is displaced a
ll fraction of a Jupiter radius from the axis of rotation,
e different from the terrestrial case, where both axes
rsect at the centre of the Earth. It was also concluded
the south magnetic pole of Jupiter was in the northern
isphere; that is, that a north-seeking compass on Jupiter
ld point south. There is nothing very bizarre about this
gestion. The Earth's magnetic field has flipped its
ction many times during its history, and it is only by

definition that the north magnetic pole is in the northern hemisphere of the Earth at the present time. From the intensity of the decimetre and decametre emission, astronomers also calculated what the energies and fluxes of electrons and protons in the Jovian magnetosphere might be.

This is a very rich array of conclusions. But all of it is remarkably inferential. The whole elaborate superstructure was put to a critical test on December 3, 1973, when the Pioneer 10 spacecraft flew through the Jovian magnetosphere. There were magnetometers aboard, which measured the strength and direction of the magnetic field at various positions in the magnetosphere; and there was a variety of charged-particle detectors, which measured energies and fluxes of the trapped electrons and protons. It is a stunning fact that virtually every one of the radio astronomical inferences was roughly confirmed by Pioneer 10 and its successor spacecraft, Pioneer 11. The surface equatorial magnetic field on Jupiter is about 6 gauss and larger at the poles. The inclination of the magnetic to the rotational axis is about 10 degrees. The magnetic axis can be described as apparently displaced about one quarter of a Jovian radius from the centre of the planet. Farther out than three Jupiter radii, the magnetic field is approximately that of a dipole; closer in, it is much more complex than had been estimated.

The flux of charged particles received by Pioneer 10 along its trajectory through the magnetosphere was considerably larger than had been anticipated – but not so large as to inactivate the spacecraft. The survival of Pioneer 10 and 11 through the Jovian magnetosphere was more the result of good luck and good engineering than of the accuracy of pre-Pioneer magnetospheric theories.

In general, the synchrotron theory of the decimetre emission from Jupiter is confirmed. All those radio astronomers turn out to have known what they were doing. We

n now believe, with much greater confidence than hereto-
re, deductions made from synchrotron physics and applied
other, more distant and less accessible cosmic objects,
ch as pulsars, quasars or supernova remnants. In fact, the
eories can now be recalibrated and their accuracy im-
oved. Theoretical radio astronomy has for the first time
en put to a critical experimental test – and it has passed
th flying colours. Of the many major findings by Pioneer
and 11, I think this is its greatest triumph: it has
nfirmed our understanding of an important branch of
smic physics.

There is much about the Jovian magnetosphere and radio
nissions that we still do not understand. The details of the
cametre emissions are still deeply mysterious. Why are
ere localized sources of decametre emission on Jupiter
obably less than 100 kilometres in size? What are these
nission sources? Why do the decametre emission regions
tate about the planet with a very high time precision –
tter than seven significant figures – but different from
e rotation periods of visible features in the Jovian clouds?
hy do the decametre bursts have a very intricate (sub-
illisecond) fine structure? Why are the decametre sources
amed – that is, not emitting in all directions equally?
hy are the decametre sources intermittent – that is, not
n' all the time?

These mysterious properties of the Jovian decametre
nission are reminiscent of the properties of pulsars. Typical
lsars have magnetic fields a trillion times larger than
piter's; they rotate 100,000 times faster; they are a
ousandth as old; they are a thousand times more massive.
he boundary of the Jovian magnetosphere moves at less
an one thousandth of the speed of the light cone of a
lsar. Nevertheless, it is possible that Jupiter is a kind of
lsar that failed, a local and quite unprepossessing model
the rapidly rotating neutron stars, which are one end

product of stellar evolution. Major insights into the stil baffling problems of pulsar emission mechanisms and magnetosphere geometries may follow from close-up spacecraft observation of Jovian decametre emission – for example, by NASA's Voyager and Galileo missions.

EXPERIMENTAL ASTROPHYSICS is developing rapidly. In another few decades at the very latest, we should see direct experimental investigation of the interstellar medium: the heliopause – the boundary between the region dominated by the solar wind and that dominated by the interstellar plasma – is estimated to lie at not much more than 100 astronomical units (9.3 billion miles) from the Earth. (Now if there were only a local solar system quasar and a backyard black hole – nothing fancy, you understand, just little baby ones – we might with *in situ* spacecraft measurements check out the greater body of modern astrophysical speculation.

If we can judge by past experience, each future venture in experimental spacecraft astrophysics will find that (a) a major school of astrophysicists was entirely right; (b) no one agreed on which school it was that was right until the spacecraft results were in; and (c) an entire new corpus of still more fascinating and fundamental problems was unveiled by the space vehicle results.

CHAPTER 20

IN DEFENCE OF ROBOTS

* * *

Thou com'st in such a questionable shape
That I will speak to thee ...

WILLIAM SHAKESPEARE,
Hamlet, Act I, Scene 4

WORD 'ROBOT', first introduced by the Czech writer el Čapek, is derived from the Slavic root for 'worker'. it signifies a machine rather than a human worker. ots, especially robots in space, have often received gatory notices in the press. We read that a human being necessary to make the terminal landing adjustments on llo 11, without which the first manned lunar landing ld have ended in disaster; that a mobile robot on the tian surface could never be as clever as astronauts in cting samples to be returned to Earth-bound geologists; that machines could never have repaired, as men did, the lab sunshade, so vital for the continuance of the Skylab sion.

ut all these comparisons turn out, naturally enough, to been written by humans. I wonder if a small self-gratulatory element, a whiff of human chauvinism, has crept into these judgments. Just as whites can sometimes ct racism and men can occasionally discern sexism, I der whether we cannot here glimpse some comparable ction of the human spirit – a disease that as yet has ame. The word 'anthropocentrism' does not mean quite same thing. The word 'humanism' has been pre-empted ther and more benign activities of our kind. From the

analogy with sexism and racism I suppose the name for th malady is 'speciesism' – the prejudice that there are n beings so fine, so capable, so reliable as human being

This is a prejudice because it is, at the very least, prejudgment, a conclusion drawn before all the facts are i Such comparisons of men and machines in space ar comparisons of smart men and dumb machines. We hav not asked what sorts of machines could have been built fo the $30-or-so billion that the Apollo and Skylab mission cost.

Each human being is a superbly constructed, astonish ingly compact, self-ambulatory computer – capable o occasion of independent decision making and real control o his or her environment. And, as the old joke goes, thes computers can be constructed by unskilled labour. But ther are serious limitations to employing human beings in certai environments. Without a great deal of protection, huma beings would be inconvenienced on the ocean floor, th surface of Venus, the deep interior of Jupiter, or even on lon space missions. Perhaps the only interesting results of Skyla that could not have been obtained by machines is tha human beings in space for a period of months undergo serious loss of bone calcium and phosphorus – which seem to imply that human beings may be incapacitated under 0 for missions of six to nine months or longer. But th minimum interplanetary voyages have characteristic time of a year or two. Because we value human beings highly we are reluctant to send them on very risky missions. If w do send human beings to exotic environments, we must als send along their food, their air, their water, amenities fo entertainment and waste recycling, and companions. B comparison, machines require no elaborate life-suppor systems, no entertainment, no companionship, and we d not yet feel any strong ethical prohibitions against sendin machines on one-way, or suicide, missions.

ertainly, for simple missions, machines have proved
nselves many times over. Unmanned vehicles have
ormed the first photography of the whole Earth and of
far side of the Moon; the first landings on the Moon,
s and Venus; and the first thorough orbital reconais-
e of another planet, in the Mariner 9 and Viking
ions to Mars. Here on Earth it is increasingly common
igh-technology manufacturing – for example, chemical
pharmaceutical plants – to be performed largely or
rely under computer control. In all these activities
hines are able, to some extent, to sense errors, to correct
akes, to alert human controllers some great distance
y about perceived problems.

he powerful abilities of computing machines to do
metic – hundreds of millions of times faster than
ded human beings – are legendary. But what about
y difficult matters? Can machines in any sense think
ugh a new problem? Can they make discussions of the
ched-contingency tree variety which we think of as
acteristically human? (That is, I ask Question 1; if the
ver is A, I ask Question 2; but if the answer is B, I ask
stion 3; and so on.) Some decades ago the English
hematician A. M. Turing described what would be
ssary for him to believe in machine intelligence. The
lition was simply that he could be in teletype com-
ication with a machine and be unable to tell that it was
human being. Turing imagined a conversation between
an and a machine of the following quality:

ROGATOR: In the first line of your sonnet which reads 'Shall I
mpare thee to a Summer's day', would not 'a Spring day' do
well or better?

ESS: It wouldn't scan.

ROGATOR: How about 'a Winter's day'? That would scan all
ht.

WITNESS: Yes, but nobody wants to be compared to a Winter
day.
INTERROGATOR: Would you say Mr. Pickwick reminded you
Christmas?
WITNESS: In a way.
INTERROGATOR: Yet Christmas is a Winter's day, and I do not thi
Mr. Pickwick would mind the comparison.
WITNESS: I don't think you're serious. By a Winter's day one mea
a typical Winter's day, rather than a special one like Christma

No device of this sophistication has yet been buil
although I am not sure how many humans would pa
Turing's human test. But the amount of effort and mone
put into artificial intelligence has been quite limited, an
there are only about a half-dozen major centres of suc
activity in the world. One of the more striking resul
obtained in a very limited universe of discourse – that
children's blocks – has come from the work of Ter
Winograd, then at the Massachusetts Institute of Tec
nology. Here is a dialogue between man and machine, th
machine having been programmed by Winograd:

Q: What does the box contain?
A: The blue pyramid and the blue box.
Q: How many blocks are not in the box?
A: Four of them.
Q: Is at least one of them narrower than the one which I told yo
to pick up?
A: Yes, the red cube.
Q: Is there a steeple?
A: Sorry, I don't know the word 'steeple'.
Q: A steeple is a stack which contains two green cubes and
pyramid, for example.
A: I understand.
Q: Are there any steeples now?
A: No.
Q: Build one.

ıe machine does. It reaches out its mechanical hand,
:s the cubes and builds the structure that has just been
ribed.

hen did you pick up the pyramid?
hile I was stacking up the red cube, the large red block and
e large green cube:
hy?
get rid of it.
ıy did you clear off that cube?
put it on the large green cube.

another example, a machine psychiatrist has been
loped by Joseph Weizenbaum, also at MIT. This is a
h simpler programme than Winograd's, since it involves
lirective psychotherapy, which, generally speaking,
ires extremely simple-minded computer programmes.
is a striking dialogue between a human being and a
puter psychotherapist. (There is certainly a selection
t here. Many other such machine/human psychiatric
ɔgues are not nearly so striking. But I suppose most
an/human psychiatric dialogues are not very striking
r.) In this interaction, in order to spell out clearly the
ective roles of therapist and patient, the computer
ıpist types upper case while the patient types lower case:

are all alike
HAT WAY
re always bugging us about something or other
YOU THINK OF A SPECIFIC EXAMPLE
my boy friend made me come here
BOY FRIEND MADE YOU COME HERE
ɔticed that i'm depressed much of the time
SORRY TO HEAR YOU ARE DEPRESSED
right. i am unhappy
OU THINK COMING HERE WILL HELP YOU NOT TO BE UNHAPPY
l some help, that much is clear

WHAT WOULD IT MEAN TO YOU IF YOU GOT SOME HELP
perhaps i could learn to get along with my mother
TELL ME MORE ABOUT YOUR FAMILY
my mother takes care of me
WHO ELSE IN YOUR FAMILY TAKES CARE OF YOU
my father
YOUR FATHER
you are like my father in some ways
WHAT RESEMBLANCE DO YOU SEE
you are not very aggressive, but i don't think you want me to no
that
WHAT MAKES YOU THINK I AM NOT VERY AGGRESSIVE
you don't argue with me
WHY DO YOU THINK I DON'T ARGUE WITH YOU
you are afraid of me
DOES IT PLEASE YOU TO BELIEVE I AM AFRAID OF YOU
it pleases my father to think i am afraid of him
WHAT ELSE COMES TO MIND WHEN YOU THINK OF YOUR FATHER
bullies
DOES THAT HAVE ANYTHING TO DO WITH THE FACT THAT YOUR
FRIEND MADE YOU COME HERE

This astonishing – one is very tempted to say 'percepti
– response from the computer is, of course, preprogramm
But, then, so are the responses of human psychotherapi
In a time when more and more people in our society seem
be in need of psychiatric counselling, and when time-shar
of computers is widespread, I can even imagine the devel
ment of a network of computer psychotherapeutic termina
something like arrays of large telephone booths, in whi
for a few dollars a session, we are able to talk to
attentive, tested and largely nondirective psychotherap
Ensuring the confidentiality of the psychiatric dialogue
one of several important steps still to be worked out.

ANOTHER SIGN of the intellectual accomplishments
machines is in games. Even exceptionally simple comput

se that can be wired by a bright ten-year-old – can be ammed to play perfect tic-tac-toe. Some computers lay world-class checkers. Chess is of course a much complicated game than tic-tac-toe or checkers. Here amming a machine to win is more difficult, and novel gies have been used, including several rather successful pts to have a computer learn from its own experience ying previous chess games. Computers can learn, for ple, empirically the rule that it is better in the beginning to control the centre of the chessboard than the hery. The ten best chess players in the world still have ng to fear from any present computer. But the situation nging. Recently a computer for the first time did well gh to enter the Minnesota State Chess Open. This may e first time that a nonhuman has entered a major ing event on the planet Earth (and I cannot help but ler if robot golfers and designated hitters may be pted sometime in the next decade, to say nothing of hins in free-style competition.) The computer did not the Chess Open, but this is the first time one has well enough to enter such a competition. Chess-playing puters are improving extremely rapidly.

ave heard machines demeaned (often with a just audible of relief) for the fact that chess is an area where human gs are still superior. This reminds me very much of the oke in which a stranger remarks with wonder on the mplishments of a checker-playing dog. The dog's owner es, 'Oh, it's not all that remarkable. He loses two games f three.' A machine that plays chess in the middle range uman expertise is a very capable machine; even if there thousands of better human chess players, there are ons who are worse. To play chess requires strategy, ight, analytical powers, and the ability to cross-late large numbers of variables and to learn from rience. These are excellent qualities in those whose job it

is to discover and explore, as well as those who watch t
baby and walk the dog.

With this as a more or less representative set of examp
of the state of development of machine intelligence, I thi
it is clear that a major effort over the next decade co
produce much more sophisticated examples. This is also
opinion of most of the workers in machine intelligence.

In thinking about this next generation of machine inte
gence, it is important to distinguish between self-control
and remotely controlled robots. A self-controlled robot h
its intelligence within it; a remotely controlled robot has
intelligence at some other place, and its successful operati
depends upon close communication between its cent
computer and itself. There are, of course, intermediate ca
where the machine may be partly self-activated and par
remotely controlled. It is this mix of remote and *in s*
control that seems to offer the highest efficiency for the n
future.

For example, we can imagine a machine designed for
mining of the ocean floor. There are enormous quantit
of manganese nodules littering the abyssal depths. Th
were once thought to have been produced by meteorite in
on Earth, but are now believed to be formed occasiona
in vast manganese fountains produced by the inter
tectonic activity of the Earth. Many other scarce a
industrially valuable minerals are likewise to be found on
deep ocean bottom. We have the capability today to des
devices that systematically swim over or crawl upon
ocean floor; that are able to perform spectrometric a
other chemical examinations of the surface material; t
can automatically radio back to ship or land all findings; a
that can mark the locales of especially valuable deposits –
example, by low-frequency radio-homing devices. The ra
beacon will then direct great mining machines to
appropriate locales. The present state of the art in deep-

ersibles and in spacecraft environmental sensors is
y compatible with the development of such devices.
ar remarks can be made for off-shore oil drilling, for
ınd other subterranean mineral mining, and so on. The
economic returns from such devices would pay not
for their development, but for the entire space
camme many times over.

ıen the machines are faced with particularly difficult
ions, they can be programmed to recognize that the
ions are beyond their abilities and to inquire of human
ıtors – working in safe and pleasant environments –
to do next. The examples just given are of devices that
ırgely self-controlled. The reverse also is possible, and
at deal of very preliminary work along these lines has
performed in the remote handling of highly radioactive
rials in laboratories of the U.S. Department of Energy.
I imagine a human being who is connected by radio link
a mobile machine. The operator is in Manila, say; the
ıine in the Mindanao Deep. The operator is attached to
ray of electronic relays, which transmits and amplifies
ıovements to the machine and which can, conversely,
what the machine finds back to his senses. So when
perator turns his head to the left, the television cameras
ıe machine turn left, and the operator sees on a great
spherical television screen around him the scene the
ine's searchlights and cameras have revealed. When the
ıtor in Manila takes a few strides forward in his wired
the machine in the abyssal depths ambles a few feet
ard. When the operator reaches out his hand, the
ıanical arm of the machine likewise extends itself; and
ɔrecision of the man/machine interaction is such that
se manipulation of material at the ocean bottom by
ıachine's fingers is possible. With such devices, human
gs can enter environments otherwise closed to them
er.

In the exploration of Mars, unmanned vehicles ha already soft-landed, and only a little further in the futu they will roam about the surface of the Red Planet, some now do on the Moon. We are not ready for manned mission to Mars. Some of us are concerned abo such missions because of the dangers of carrying terrestr microbes to Mars, and Martian microbes, if they exist, Earth, but also because of their enormous expense. T Viking landers deposited on Mars in the summer of 19 have a very interesting array of sensors and scienti instruments, which are the extension of human senses to alien environment.

The obvious post-Viking device for Martian exploratio one which takes advantage of the Viking technology, is Viking Rover in which the equivalent of an entire Viki spacecraft, but with considerably improved science, is put wheels or tractor treads and permitted to rove slowly ov the Martian landscape. But now we come to a new proble one that is never encountered in machine operation on t Earth's surface. Although Mars is the second closest plan it is so far from the Earth that the light travel time becom significant. At a typical relative position of Mars and t Earth, the planet is 20 light-minutes away. Thus, if the spa craft were confronted with a steep incline, it might send message of inquiry back to Earth. Forty minutes later t response would arrive saying something like 'For heave sake, stand dead still.' But by then, of course, an u sophisticated machine would have tumbled into the gul Consequently, any Martian Rover requires slope and roug ness sensors. Fortunately, these are readily available a are even seen in some children's toys. When confronted w a precipitous slope or large boulder, the spacecraft wou either stop until receiving instructions from the Earth response to its query (and televised picture of the terrai or back off and start in another and safer direction.

uch more elaborate contingency decision networks can uilt into the onboard computers of spacecraft of the s. For more remote objectives, to be explored further in uture, we can imagine human controllers in orbit nd the target planet, or on one of its moons. In the ration of Jupiter, for example, I can imagine the tors on a small moon outside the fierce Jovian tion belts, controlling with only a few seconds' delay esponses of a spacecraft floating in the dense Jovian ls.

uman beings on Earth can also be in such an interaction , if they are willing to spend some time on the enter- . If every decision in Martian exploration must be hrough a human controller on Earth, the Rover can rse only a few feet an hour. But the lifetimes of such rs are so long that a few feet an hour represents a ctly respectable rate of progress. However, as we ine expeditions into the farthest reaches of the solar m – and ultimately to the stars – it is clear that ontrolled machine intelligence will assume heavier ens of responsibility.

the development of such machines we find a kind of ergent evolution. Viking is, in a curious sense, like great outsized, clumsily constructed insect. It is not ambulatory, and it is certainly incapable of self- duction. But it has an exoskeleton, it has a wide range sectlike sensory organs, and it is about as intelligent as gonfly. But Viking has an advantage that insects do it can, on occasion, by inquiring of its controllers on h, assume the intelligence of a human being – the rollers are able to reprogramme the Viking computer on asis of decisions they make.

the field of machine intelligence advances and as asingly distant objects in the solar system become sible to exploration, we will see the development of

increasingly sophisticated onboard computers, slow
climbing the phylogenetic tree from insect intelligence
crocodile intelligence to squirrel intelligence and – in the n
very remote future, I think – to dog intelligence. Any flig
to the outer solar system must have a computer capable
determining whether it is working properly. There is
possibility of sending to the Earth for a repairman. T
machine must be able to sense when it is sick and skilfu
doctor its own illnesses. A computer is needed that is ab
either to fix or replace failed computer, sensor or structu
components. Such a computer, which has been called STA
(self-testing and repairing computer), is on the thresho
of development. It employs redundant components,
biology does – we have two lungs and two kidneys part
because each is protection against failure of the other. B
a computer can be much more redundant than a hum
being, who has, for example, but one head and one hea

Because of the weight premium on deep space explorato
ventures, there will be strong pressures for continu
miniaturization of intelligent machines. It is clear th
remarkable miniaturization has already occurred: vacuu
tubes have been replaced by transistors, wired circuits
printed circuit boards, and entire computer systems
silicon-chip microcircuitry. Today a circuit that used
occupy much of a 1930 radio set can be printed on the
of a pin. If intelligent machines for terrestrial mining a
space exploratory applications are pursued, the time cann
be far off when household and other domestic robots w
become commercially feasible. Unlike the classical anthr
poid robots of science fiction, there is no reason for su
machines to look any more human than a vacuum clean
does. They will be specialized for their functions. But the
are many common tasks, ranging from bartending to flo
washing, that involve a very limited array of intellectu
capabilities, albeit substantial stamina and patience. A

ose ambulatory household robots, which perform
:stic functions as well as a proper nineteenth-century
sh butler, are probably many decades off. But more
alized machines, each adapted to a specific household
ion, are probably already on the horizon.

is possible to imagine many other civic tasks and
tial functions of everyday life carried out by intelligent
·ines. By the early 1970s, garbage collectors in
orage, Alaska, and other cities won wage settlements
nteeing them salaries of about $20,000 per annum. It
ssible that the economic pressures alone may make a
:asive case for the development of automated garbage-
:ting machines. For the development of domestic and
robots to be a general civic good, the effective re-
oyment of those human beings displaced by the robots
, of course, be arranged; but over a human generation
should not be too difficult – particularly if there are
htened educational reforms. Human beings enjoy
ing.

e appear to be on the verge of developing a wide variety
·telligent machines capable of performing tasks too
erous, too expensive, too onerous or too boring for
n beings. The development of such machines is, in my
, one of the few legitimate 'spin-offs' of the space
:amme. The efficient exploitation of energy in agricul-
- upon which our survival as a species depends – may
be contingent on the development of such machines.
main obstacle seems to be a very human problem, the
feeling that comes stealthily and unbidden, and argues
there is something threatening or 'inhuman' about
ines performing certain tasks as well as or better than
n beings; or a sense of loathing for creatures made
icon and germanium rather than proteins and nucleic
. But in many respects our survival as a species depends
r transcending such primitive chauvinisms. In part, our

adjustment to intelligent machines is a matter of acclimatiz
tion. There are already cardiac pacemakers that can ser
the beat of the human heart; only when there is the slight
hint of fibrillation does the pacemaker stimulate the hea
This is a mild but very useful sort of machine intelligen
I cannot imagine the wearer of this device resenting its inte
gence. I think in a relatively short period of time the
will be a very similar sort of acceptance for much mo
intelligent and sophisticated machines. There is nothi
inhuman about an intelligent machine; it is indeed
expression of those superb intellectual capabilities that or
human beings, of all the creatures on our planet, no
possess.

CHAPTER 21

THE PAST AND FUTURE OF AMERICAN ASTRONOMY

* * *

'What has been done is little – scarcely a beginning; yet it is much in comparison with the total blank of a century past. And our knowledge will, we are easily persuaded, appear in turn the merest ignorance to those who come after us. Yet it is not to be despised, since by it we reach up groping to touch the hem of the garment of the Most High.

AGNES M. CLERKE,
A Popular History of Astronomy
(London, Adam and Charles Black, 1893)

WORLD has changed since 1899, but there are few fields h have changed more – in the development of fundaal insights and in the discovery of new phenomena – astronomy. Here are a few titles of recent papers ished in the scientific magazines *The Astrophysical nal* and *Icarus:* 'G240–72: A New Magnetic White rf with Unusual Polarization', 'Relativistic Stellar ility: Preferred Frame Effects', 'Detection of Interstellar ıylamine', 'A New List of 52 Degenerate Stars', 'The of Alpha Centauri', 'Do OB Runaways Have Collapsed panions?', 'Finite Nuclear-size Effects on Neutrino-Bremsstrahlung in Neutron Stars', 'Gravitational iation from Stellar Collapse', 'A Search for a Cosmoal Component of the Soft X-ray Background in the ction of M31', 'The Photochemistry of Hydrocarbons e Atmosphere of Titan', 'The Content of Uranium, rium and Potassium in the Rocks of Venus as Measured

by Venera 8', 'HCN Radio Emission from Comet Koho tek', 'A Radar Brightness and Altitude Image of a Portic of Venus' and 'A Mariner 9 Photographic Atlas of t Moons of Mars'. Our astronomical ancestors would ha extracted a glimmer of meaning from these titles, but think their principal reaction would have been one incredulity.

WHEN I WAS ASKED to chair the 75th Anniversary Committ of the American Astronomical Society in 1974, I thought would provide a pleasant opportunity to acquaint myse with the state of our subject at the end of the past centur I was interested to see where we had been, where we a today, and if possible, something of where we may be goin In 1897 the Yerkes Observatory, then the largest telesco in the world, was given a formal dedication, and a scientif meeting of astronomers and astrophysicists was held connection with the ceremony. A second meeting was he at the Harvard College Observatory in 1898 and a third the Yerkes Observatory in 1899, by which time what is no the American Astronomical Society had been official founded.

The astronomy of 1897 to 1899 seems to have bee vigorous, combative, dominated by a few strong pe sonalities and aided by remarkably short publication time The average time between submission and publication f papers in the *Astrophysical Journal* (*Ap. J.*) in this perio seems to be better than in *Astrophysical Journal Lette* today. The fact that a great many papers were from t Yerkes Observatory, where the journal was edited, may ha had something to do with this. The opening of the Yerk Observatory at Williams Bay, Wisconsin – which has t year 1895 imprinted upon it – was delayed more than a ye because of the collapse of the floor, which narrowly misse killing the astronomer E. E. Barnard. The accident

ioned in *Ap. J.* (6:149), but one finds no hint of gence there. However, the British journal *Observatory* 93), clearly implies careless construction and a cover-up ield those responsible. We also discover on the same of *Observatory* that the dedication ceremonies were oned for some weeks to accommodate the travel ule of Mr. Yerkes, the robber-baron donor. The physical Journal says that 'the dedication ceremonies necessarily postponed from October 1, 1897', but does ay why.

. *J.* was edited by George Ellery Hale, the director of erkes Observatory, and by James E. Keeler, who in became the director of the Lick Observatory on Mount ilton in California. However, there was a certain nation of *Ap. J.* by Williams Bay, perhaps because the Observatory dominated the *Publications* of the Astro- cal Society of the Pacific (*PASP*) in the same period. me 5 of the *Astrophysical Journal* has no fewer than en plates of the Yerkes Observatory, including one of owerhouse. The first fifty pages of Volume 6 have a more plates of the Yerkes Observatory. The Eastern nance of the American Astronomical Society is also ted by the fact that the first president of the Astro- cal and Astrophysical Society of America was Simon comb, of the Naval Observatory in Washington, and irst vice presidents, Young and Hale. West Coast nomers complained about the difficulties in travelling third conference of astronomers and astrophysicists at es and seem to have voiced some pleasure that promised nstrations with the Yerkes 40-inch refractor for this nony had to be postponed because of cloudy weather. was about the most in the way of interobservatory our that can be found in either journal.

t in the same period *Observatory* had a keen nose for rican astronomical gossip. From *Observatory* we find

that there was a 'civil war' at the Lick Observatory and
'scandal' associated with Edward Holden (the directo
before Keeler), who is said to have permitted rats in th
drinking water at Mount Hamilton. It also published a stor
about a test chemical explosion scheduled to go off in th
San Francisco Bay Area and to be monitored by a seismi
device on Mount Hamilton. At the appointed moment, n
staff member could see any sign of needle deflection excep
for Holden, who promptly dispatched a messenger dow
the mountain to alert the world to the great sensitivity o
the Lick seismometer. But soon up the mountain cam
another messenger with the news that the test had bee
postponed. A much faster messenger was then dispatche
to overtake the first and an embarrassment to the Lic
Observatory was, *Observatory* notes, narrowly averted.

The youth of American astronomy in this period i
eloquently reflected in the proud announcement in 1900 tha
the Berkeley Astronomical Department would hencefort
be independent of the Civil Engineering Department at th
University of California. A survey by Professor George Airy
later the British Astronomer Royal, regretted being unabl
to report on astronomy in America in 1832 becaus
essentially there was none. He would not have said that i
1899.

There is never much sign in these journals of the intrusio
of external (as opposed to academic) politics, except fo
an occasional notice such as the appointment by Presider
McKinley of T.J.J. See as professor of mathematics to th
US Navy, and a certain continuing chilliness in scientif
debates between the personnel of the Lick and Potsda
(Germany) Observatories.

Some signs of the prevailing attitudes of the 189
occasionally trickle through. For example, in a descriptio
of an eclipse expedition to Siloam, Georgia, on May 2
1900: 'Even some of the whites were lacking in a very dee

nowledge of things "eclipse-wise". Many thought it was money-making scheme and what I intended to charge for lmission was a very important question, frequently asked. nother idea was that the eclipse could be seen only from e inside of my observatory ... Just here I wish to express y appreciation of the high moral tone of the community, r, with a population of only 100, including the immediate ighbourhood, it sustains 2 white and 2 coloured churches d during my stay I did not hear a single profane word ... s an unsophisticated Yankee in the Southland, unused to uthern ways, I naturally made many little slips that were t considered "just the thing". The smiles at my prefixing Mr." to the name of my coloured helper caused me to ange it to "Colonel", which was entirely satisfactory to erybody.'

A board of visitors was appointed to resolve some (never blicly specified) problems at the US Naval Observatory. report of this group – which consisted of two obscure nators and Professors Edward C. Pickering, George C. omstock and Hale – is illuminating because it mentions llar amounts. We find that the annual running costs of e major observatories in the world were: Naval Observa- ry, $85,000; Paris Observatory, $53,000; Greenwich bservatory (England), $49,000; Harvard Observatory, 6,000; and Pulkowa Observatory (Russia), $36,000. The laries of the two directors of the US Naval Observatory ere $4,000 each, and at the Harvard Observatory, $5,000. he distinguished board of visitors recommended that in a chedule of salaries which could be expected to attract tronomers of the class desired', the salary of directors of servatories should be $6,000. At the Naval Observatory, mputers (exclusively human at the time) were paid $1,200 r annum, but at the Harvard Observatory only $500 per nnum, and were almost exclusively women. In fact, all laries at Harvard, except for the director's, were signifi-

cantly lower than at the Naval Observatory. The committe stated: 'The great difference in salaries at Washington an Cambridge, especially for the officers of lower grade, i probably unavoidable. This is partly due to Civil Servic Rules.' An additional sign of astronomical impecuniosity i the announcement of the post of 'volunteer researc assistant' at Yerkes, which had no associated pay but whic was said to provide good experience for students with highe degrees.

Then, as now, astronomy was besieged by 'paradoxers' proponents of fringe or crackpot ideas. One proposed telescope with ninety-one lenses in series as an alternativ to a telescope with a smaller number of lenses of large aperture. The British in this period were similarly plague but in perhaps a gentler way. For example, an obituary i the *Monthly Notices* of the Royal Astronomical Societ (59–226) of Henry Perigal informs us that the deceased ha celebrated his ninety-fourth birthday by becoming a membe of the Royal Institution, but was elected a Fellow of th Royal Astronomical Society in 1850. However, 'our pub lications contain nothing from his pen.' The obituary describes 'the remarkable way in which the charm of Mr Perigal's personality won him a place which might hav seemed impossible of attainment for a man of his views for there is no masking the fact that he was a paradoxe pure and simple, his main conviction being that the Moo did not rotate, and his main astronomical aim in life bein to convince others, and especially young men not hardene in the opposite belief, of their grave error. To this end h made diagrams, constructed models, and wrote poems bearing with heroic cheerfulness the continued disappoint ment of finding none of them of any avail. He has, however done excellent work apart from this unfortunate misunder standing.'

The number of American astronomers in this period wa

y small. The by-laws of the Astronomical and Astro-
sical Society of America state that a quorum is con-
uted by twenty members. By the year 1900 only nine
torates had been granted in astronomy in America. In
t year there were four astronomical doctorates: two from
umbia University for G. N. Bauer and Carolyn Furness;
from the University of Chicago for Forest Ray
ulton; and one from Princeton University for Henry
rris Russell.

Some idea of what was considered important scientific
rk in this period can be garnered from the prizes that
e awarded. E. E. Barnard received the Gold Medal of
Royal Astronomical Society in part for his discovery of
Jovian moon Jupiter 5 and for his astronomical
otography with a portrait lens. His steamer, however, was
ght in an Atlantic storm, and he did not arrive in time
the celebration ceremony. He is described as requiring
eral days to recover from the storm, whereupon the
AS hospitably gave a second dinner for him. Barnard's
ture seems to have been spectacular and made full use of
t recently improved audio-visual aid, the lantern slide
jector.

n his discussion of his photograph of the region of the
lky Way near Theta Ophiuchus he concluded that 'the
ire groundwork of the Milky Way ... has a substratum
nebulous matter.' (Meanwhile H. K. Palmer reported no
ulosity in photographs of the globular cluster M13.)
rnard, who was a superb visual observer, expressed
siderable doubts about Percival Lowell's view of an
abited and canal-infested Mars. In his thanks to Barnard
his lecture, the president of the Royal Astronomical
iety, Sir Robert Ball, voiced concern that henceforth he
ould regard the canals in Mars with some suspicion, nay,
n the seas [of Mars, the dark areas] had partly fallen
ler a ban. Perhaps the lecturer's recent experiences on the

Atlantic might explain something of this mistrust.' Lowell views were not then in favour in England, as another notic in *Observatory* indicated. In response to an inquiry on whic books had most pleased and interested him in 1896, Pro fessor Norman Lockyer replied, '*Mars* by Percival Lowel *Sentimental Tommy* by J. M. Barrie. (No Time for Readin Seriously).'

Prizes in astronomy for 1989 awarded by the Académ Française included one to Seth Chandler for the discovery o the variation in latitude; one to Belopolsky, partly fo studies of spectroscopic binary stars; and one to Schott fo work on terrestrial magnetism. There was also a priz competition for the best treatise on 'the theory of pe turbations of Hyperion', a moon of Saturn. We are informe that 'the only essay presented was that by Dr. G. W. Hi of Washington to whom the prize was awarded.'

The Astronomical Society of the Pacific's Bruce Med was awarded in 1899 to Dr. Arthur Auwers of Berlin. Th dedicatory address included the following remarks: 'Toda Auwers stands at the head of German astronomy. In him seen the highest type of investigator in our time, one perhap better developed in Germany than in any other countr The work of men of this type is marked by minute an careful research, untiring industry in the accumulation o facts, caution in propounding new theories or explanation and, above all, the absence of effort to gain recognition b being the first to make a discovery.' In 1899 the Henr Draper Gold Medal of the National Academy of Science was presented for the first time in seven years. The recipien was Keeler. In 1898 Brooks, whose observatory was i Geneva, New York, announced the discovery of his twenty first comet – which Brooks described as 'achieving h majority'. Shortly thereafter he received the Lalande Prize o the Académie Française for his record in discovering comet

In 1897, in connection with an exhibition in Brussels, th

gian government offered prizes for the solutions of ain problems in astronomy. These problems included numerical value of the acceleration due to gravity on th, the secular acceleration of the Moon, the net motion he solar system through space, the variation of latitude, photography of planetary surfaces, and the nature of the ıls of Mars. A final topic was the invention of a method)bserve the solar corona in the absence of an eclipse. *ıthly Notices* (20:145) commented: '... if this pecuniary ard does induce anyone to solve this last problem or in any of the others, we think the money will be well spent.' lowever, reading the scientific papers of this time, one the impression that the focus had shifted to other topics n those for which prizes were being given. Sir William and y Huggins performed laboratory experiments which wed that at low pressures the emission spectrum of

HUGGINS' STELLAR SPECTRAL SEQUENCE

er of easing Age	*Star (and modern spectral type in parentheses)*	
ıng	Sirius (A1V)	Vega (A0V)
	.....	
	Altair (A7 IV–V)	
	Rigel (B8Ia)	
	Deneb (A2Ia)	
	.....	
	.....	
	Capella (G8, G0)	Sun (G0)
	Arcturus (K1 III)	
	Aldebaran (K5 III)	
	Betelgeuse (M2 I)	

: The modern stellar spectral sequence runs, from 'early' to 'late' tral types, as O, B, A, F, B, K, M. Huggins was very nearly right.

calcium exhibited only the so-called H and K lines. The concluded that the Sun was composed chiefly of hydroge helium, 'coronium' and calcium. Huggins had earlier estab lished a stellar spectral sequence, which he believed wa evolutionary. The Darwinian influence in science was ver strong in this period, and among American astronome T. J. J. See's work was notably dominated by a Darwinia perspective. It is interesting to compare Huggins' spectra sequence with the present Morgan-Keenan spectral types

We can see here the origin of the present terms 'early' an 'late' spectral type, which reflect the Darwinian spirit of late Victorian science. It is also clear that there is a reasonabl continuous gradation of spectral types here, and th beginnings – through the later Hertzsprung-Russell diagra – of modern theories of stellar evolution.

There were major developments in physics during thi period and readers of *Ap. J.* were alerted to them by th reprinting of summaries of important papers. Experimen were still being performed on the basic radiation laws. I some papers, the level of physical sophistication was not o the highest calibre, as, for example, in an article in *PAS* (11:18) where the linear momentum of Mars is calculate as the single product of the mass of the planet and the linea velocity of the surface. It concluded 'the planet, exclusive o the cap, has a momentum of 183 and 3/8 septillion foo pounds.' Exponential notation for large numbers wa evidently not in wide use.

In this time we have the publication of visual and photo graphic light curves, for example, of stars in M5; an experiments in filter photography of Orion by Keeler. A obviously exciting topic was time-variable astronomy, whic must then have generated something of the excitement tha pulsars, quasars and X-ray sources do today. There wer many studies of variable velocities in the line of sight fro which were derived the orbits of spectroscopic binaries, a

. as periodic variations in the apparent velocity of
icron Ceti from the Doppler displacement of H gamma
other spectral lines.

he first infrared measurements of stars were performed
ie Yerkes Observatory by Ernest F. Nichols. The study
:ludes: 'We do not receive from Arcturus more heat than
:ld reach us from a candle at a distance of 5 or 6 miles.'
further calculations are given. The first experimental
ervations of the infrared opacity of carbon dioxide and
er vapour were performed in this period by Rubens and
hkinass, who essentially discovered the v_2 fundamental
:arbon dioxide at 15 microns and the pure rotation
:trum of water.

here is preliminary photographic spectroscopy of the
lromeda nebula by Julius Scheiner at Potsdam,
many, who concludes correctly that 'the previous sus-
on that the spiral nebulae are star clusters is now raised
certainty.' As an example of the level of personal
peration tolerated at this time, the following is an extract
n a paper by Scheiner in which W. W. Campbell is
cized: 'In the November number of the *Astrophysical*
rnal, Professor Campbell attacks, with much indig-
on, some remarks of mine criticizing his discoveries ...
h sensitiveness is somewhat surprising on the part of one
is himself given to severely taking others to task.
ther, an astronomer who frequently observes phen-
na which others cannot see, and fails to see those which
:rs can, must be prepared to have his opinions contested.
s Professor Campbell complains, I have only supported
views by a single example, I was only withheld by
rteous motives from adding another. Namely, the fact
Professor Campbell cannot perceive the lines of
eous vapour in the spectrum of Mars which were seen
Huggins and Vogel in the first place, and, after Mr.
ipbell had called their existence in question, were again

seen and identified with certainty by Professor Wilsing and myself.' The amount of water vapour in the Martian atmosphere that is now known to exist would have been entirely undetectable by the spectroscopic methods then in use.

Spectroscopy was a dominant element in late-nineteenth century science. *Ap. J.* was busily publishing Rowland's solar spectrum, which ran to 20,000 wavelengths, each to seven significant figures. It published a major obituary of Bunsen. Occasionally the astronomers took note of the extraordinary nature of their discoveries: 'It is simply amazing that the feeble twinkling light of a star can be made to produce such an autographic record of substance and condition of the inconceivably distant luminary.' A major topic of debate for the *Astrophysical Journal* was whether spectra should be shown with red to the left or to the right. Those who favoured red to the left cited the analogy of the piano (where high frequencies are to the right), but *Ap. J.* opted gamely for red to the right. Some room for compromise was available on whether, in lists of wavelengths, red should be at the top or at the bottom. Feelings ran high, and Huggins wrote to say that 'any change ... would be little less than intolerable'. But the *Ap. J.* won anyway.

Another major discussion in this period was on the nature of sunspots. G. Johnstone Stoney proposed that they were caused by a layer of condensed clouds in the photosphere of the Sun. But Wilson and FitzGerald objected to this on the ground that no conceivable condensates could exist at these high temperatures, with the possible exception of carbon. They suggested instead and very vaguely that sunspots are due to 'reflection by convection streams of gas'. Evershed had a more ingenious idea. He thought that sunspots were holes in the outer photosphere of the Sun permitting us to see to much greater and hotter depths. But

y are they dark? He proposed that all the radiation would moved from the visible to the inaccessible ultraviolet. is, of course, was before the Planck distribution of liation from a hot object was understood. It was not at s time thought impossible that the spectral distributions black bodies of different temperatures should cross; and ne experimental curves of this period indeed showed such ssing – due, as we now know, to emissivity and absorp- ity differences.

Ramsay had recently discovered the element krypton, ich was said to have, among fourteen detectable spectral es, one at 5570 Å, coincident with 'the principal line of the rora'. E. B. Frost concluded: 'Thus it seems that the true igin of that hitherto perplexing line has been discovered.' e now know it is due to oxygen.

There were a great many papers on instrumental design, e of the more interesting being by Hale. In January 1897 suggested that both refracting and reflecting telescopes re needed, but noted that there was a clear movement wards reflectors, especially equatorial coude telescopes. In historical memoir, Hale mentions that the 40-inch lens s available to the Yerkes Observatory only because a evious plan to build a large refractor near Pasadena, lifornia, had fallen through. What, I wonder, would the story of astronomy have been like if the plan had ceeded? Curiously enough, Pasadena seems to have made offer to the University of Chicago to have the Yerkes bservatory situated there. It would have been a long mmute for 1897.

AT THE END of the nineteenth century, solar system studies splayed the same mixture of future promise and current nfusion that the stellar work did. One of the most notable pers of the period, by Henry Norris Russell, is called 'The tmosphere of Venus'. It is a discussion of the extension

of the cusps of the crescent Venus, based in part on th author's observations with the 5-inch *finder* telescope of th 'great equatorial' of the Halsted Observatory at Princeto Perhaps the young Russell was not yet considered full reliable operating larger telescopes at Princeton. The essenc of the analysis is correct by present standards. Russell con cluded that refraction of sunlight was not responsible for th extension of the cusps, and that the cause was to be foun in the scattering of sunlight: '... the atmosphere of Venus like our own, contains suspended particles of dust or fog o some sort, and ... what we see is the upper part of thi hazy atmosphere, illuminated by rays that have passed clos to the planet's surface.' He later says that the apparen surface may be a dense cloud layer. The height of the haz is calculated as about 1 kilometre above what we would no call the main cloud deck, a number that is just consisten with limb photography by the Mariner 10 spacecraft Russell thought, from the work of others, that there wa some spectroscopic evidence for water vapour and oxygen i a thin Venus atmosphere. But the essence of his argumen has stood the test of time remarkably well.

William H. Pickering's discovery of Phoebe, the outer most satellite of Saturn, was announced; and Andrew E Douglass of the Lowell Observatory published observation that led him to conclude that Jupiter 3 rotates about on hour slower than its period of revolution, a conclusio incorrect by one hour.

Others who estimated periods of rotation were not quit so successful. For example, there was a Leo Brenner wh observed from the Manora Observatory in a place calle Lussinpiccolo. Brenner severely criticized Percival Lowell' estimate of the rotation period of Venus. Brenner himsel compared two drawings of Venus in white light made by tw different people four years apart – from which he deduce a rotation period of 23 hours, 57 minutes and 36.3772

onds, which he said agreed well with the mean of his own ost reliable' drawings. Considering this, Brenner found it omprehensible that there could still be partisans of a .7-day rotation period and concluded that 'an in-erienced observer, an unsuitable telescope, an unhappily sen eyepiece, a very small diameter of the planet, erved with an insufficient power, and a low declination, ogether explained Mr. Lowell's peculiar drawings.' The h, of course, lies not between the extremes of Lowell Brenner, but rather at the other end of the scale, with inus sign, a retrograde period of 243 days.

n another communication Herr Brenner begins: 'Gentle-n: I have the honour to inform you that Mrs. Manora has covered a new division in the Saturnian ring system' – n which *we* discover that there is a *Mrs.* Manora at the nora Observatory in Lussinpiccolo and that she per-ns observations along with Herr Brenner. Then follows escription of how the Encke, Cassini, Antoniadi, Struve Manora divisions are all to be kept straight. Only the two have stood the test of time. Herr Brenner seems ave faded into the mists of the nineteenth century.

THE SECOND CONFERENCE of Astronomers and Astro-sicists at Cambridge, there was a paper on the 'sug-ion' that asteroid rotation, if any, might be deduced n a light curve. But no variation of the brightness with e was found, and Henry Parkhurst concluded: 'I think it afe to dismiss the theory.' It is now a cornerstone of roid studies.

n a discussion of the thermal properties of the Moon, le independently of the one-dimensional equation of t conduction but based on laboratory emissivity surements, Frank Very concluded that a typical lunar time temperature is about 100°C – exactly the right wer. His conclusion is worth quoting: 'Only the most

terrible of Earth's deserts where the burning sands blister th skin, and the men, beasts, and birds drop dead, can approac noontide on the cloudless surface of our satellite. Only th extreme polar latitudes of the Moon can have an endurab temperature by day, to say nothing of the night, when w should have to become troglodytes to preserve ourselv from such intense cold.' The expository styles were ofte fine.

Earlier in the decade, Maurice Loewy and Pierre Puiseu at the Paris Observatory had published an atlas of luna photographs, the theoretical consequences of which we discussed in *Ap. J.* (5:51). The Paris group proposed modified volcanic theory for the origin of the lunar crater rills and other topographic forms, which was later criticize by E. E. Barnard after he examined the planet with th 40-inch telescope. Barnard was then criticized by the Roy Astronomical Society for his criticism, and so on. One of th arguments in this debate had a deceptive simplicity: vo canoes produce water; there is no water on the moon; ther fore the lunar craters are not volcanic. While most of th lunar craters are not volcanic, this is not a convincin argument because it neglects the problem of possib repositories for water. Very's conclusions on the tempera ture of the lunar poles could have been read with som profit. Water there freezes out as frost. The other possibili is that water might escape from the Moon to space.

This was recognized by Stoney in a remarkable pap called 'Of Atmospheres upon Planets and Satellites'. H deduced that there should be no lunar atmosphere becaus of the very rapid escape to space of gases from the lo lunar gravity, or any large build-up of the lightest gase hydrogen and helium, on Earth. He believed that there wa no water vapour in the Martian atmosphere and that Mar atmosphere and caps were probably carbon dioxide. H implied that hydrogen and helium were to be expected o

iter, and that Triton, the largest moon of Neptune, ght have an atmosphere. Each of these conclusions is in ord with present-day findings or opinions. He also con- led that Titan should be airless, a prediction with which ne modern theorists agree – although Titan seems to have ther view of the matter (see Chapter 13).

n this period there are also a few breath-taking specu- ons, such as one by the Rev. J. M. Bacon that it would n good idea to perform astronomical observations from h altitudes – from, for example, a free balloon. He gested that there would be at least two advantages: better ng and ultraviolet spectroscopy. Goddard later made ilar proposals for rocket-launched observatories (Chapter .

Hermann Vogel had previously found, by eyeball spectro- py, an absorption band at 6183 Å in the body of urn. Subsequently the International Color Photo mpany of Chicago made photographic plates, which were good that wavelengths as long as H Alpha in the red ld be detected for a fifth-magnitude star. This new ulsion was used at Yerkes, and Hale reported that there no sign of the 6183 Å band for the rings of Saturn. band is now known to be at 6190 Å and is $6\nu_3$ of methane.

Another reaction to Percival Lowell's writings can be ined from the address of James Keeler at the dedication he Yerkes Observatory:

> is to be regretted that the habitability of the planets, a subject which astronomers profess to know little, has been chosen as eme for exploitation by the romancer, to whom the step from itability to inhabitants is a very short one. The result of his nuity is that fact and fancy become inextricably tangled in the d of the layman, who learns to regard communication with inhabitants of Mars as a project deserving serious consideration which he may even wish to give money to scientific societies), who does not know that it is condemned as a vagary by the

very men whose labours have excited the imagination of t
novelist. When he is made to understand the true state of o
knowledge of these subjects, he is much disappointed and feels
certain resentment towards science, as if it had imposed upon hi
Science is not responsible for these erroneous ideas, which, havi
no solid basis, gradually die out and are forgotten.

The address of Simon Newcomb on this occasion contai
some remarks which apply generally, if a little idealisticall
to the scientific endeavour:

> Is the man thus moved into the exploration of nature by a
> unconquerable passion more to be envied or pitied? In no oth
> pursuit does such certainty come to him who deserves it. No life
> so enjoyable as that whose energies are devoted to following o
> the inborn impulses of one's nature. The investigator of truth
> little subject to the disappointments which await the ambitio
> man in other fields of activity. It is pleasant to be one of
> brotherhood extending over the world in which no rivalry exis
> except that which comes out of trying to do better work tha
> anyone else, while mutual admiration stifles jealousy ... As t
> great captain of industry is moved by the love of wealth and t
> politician by the love of power, so the astronomer is moved b
> the love of knowledge for its own sake and not for the sake of i
> application. Yet he is proud to know that his science has been wort
> more to mankind than it has cost ... He feels that man does not liv
> by bread alone. If it is not more than bread to know the place w
> occupy in the universe, it is certainly something that we shou
> place not far behind the means of subsistence.

AFTER READING through the publications of astronomer
three-quarters of a century ago, I felt an irresistible tempta
tion to imagine the 150th Anniversary Meeting of th
American Astronomical Society – or whatever name it wi
have metamorphosed into by then – and guess how ou
present endeavours will be viewed.

In examining the late-nineteenth-century literature, we ar

sed at some of the debates on sunspots, and impressed
the Zeeman effect was not considered a laboratory
osity but something to which astronomers should devote
siderable attention. These two threads intertwined, as if
igured, a few years later in G. E. Hale's discovery of
e magnetic field strengths in sunspots.

kewise we find innumerable papers in which the
ence of a stellar evolution is assumed but its nature
ains hidden; in which the Kelvin-Helmholtz gravita-
al contraction was considered the only possible stellar
gy source, and nuclear energy remained entirely un-
cipated. But at the same time, and sometimes in the same
me of the *Astrophysical Journal*, there is acknowledg-
t of curious work being done on radioactivity by a man
ed Becquerel in France. Here again we see the two
urently unrelated threads moving through our few-years
oshot of late-nineteenth-century astronomy and destined
ntertwine forty years later.

here are many related examples – for instance, in the
rpretation of series spectra of nonhydrogenic elements
ined at the telescope and pursued in the laboratory.
physics and new astronomy were the complementary
s of the emerging science of astrophysics.

ccordingly, it is difficult not to wonder how many of the
est present debates – for example, on the nature of
ars, or the properties of black holes, or the emission
metry of pulsars – must await an intertwining with new
lopments in physics. If the experience of seventy-five
s ago is any guide, there will already be people today
dimly guess which physics will join with which
onomy. And a few years later, the connection will be
sidered obvious.

e also see in the nineteenth-century material a number
ases where the observational methods or their interpre-
ons are clearly in default by present standards. Planetary

periods deduced to ten significant figures by the compariso of two drawings made by different people of features w now know to be unreal to begin with is one of the wor examples. But there are many others, including a plethora ' 'double-star measurements' of widely separated object which are mainly physically unconnected stars; a fascinatio with pressure and other effects on the frequencies of spectr lines when no one is paying any attention to curve ' growth analysis; and acrimonious debates on the presen or absence of some substance based solely upon naked-ey spectroscopy.

Also curious is the sparseness of the physics in lat Victorian astrophysics. Reasonably sophisticated physics almost exclusively the province of geometrical and physic optics, the photographic process, and celestial mechanic To make theories of stellar evolution based on stellar spectr without wondering much about the dependence of excit tion and ionization on temperature, or attempting to ca culate the subsurface temperature of the Moon without ev solving Fourier's equation of heat conduction seem to me t be less than quaint. In seeing elaborate empirical represent tions of laboratory spectra, the modern reader becom impatient for Bohr and Schrödinger and their successors t come along and develop quantum mechanics.

I wonder how many of our present debates and mo celebrated theories will appear, from the vantage point of th year 2049, marked by shoddy observations, indifferen intellectual powers or inadequate physical insight. I have th sense that we are today more self-critical than scientists we in 1899; that because of the larger population of astro omers, we check each other's results more often; and tha in part because of the existence of organizations like th American Astronomical Society, the standards of exchang and discussion of results have risen significantly. I hope ou colleagues of 2049 will agree.

he major advance between 1899 and 1974 must be sidered technological. But in 1899 the world's largest actor had been built. It is still the world's largest actor. A reflector of 100-inch aperture was beginning to onsidered. We have improved on that aperture only by tor of two in the intervening years. But what would our agues of 1899 – living after Hertz but before Marconi ve made of the Arecibo Observatory, or the Very Large y, or Very Long Baseline Interferometry (VLBI)? Or king out the debate on the period of rotation of Mercury adar Doppler spectroscopy? Or testing the nature of the r surface by returning some of it to Earth? Or pursuing problem of the nature and habitability of Mars by ting it for a year and returning 7,200 photographs of it, of higher quality than the best 1899 photographs of Moon? Or landing on the planet with imaging systems, obiology experimentation, seismometers and gas matograph/mass spectrometers, which did not even ely exist in 1899? Or testing cosmological models by tal ultraviolet spectroscopy of interstellar deuterium – n neither the models to be tested nor the existence of atom that tests it were known in 1899, much less the nique of observation?

is clear that in the past seventy-five years American world astronomy has moved enormously beyond even most romantic speculations of the late-Victorian astron-rs. And in the next seventy-five years? It is possible to e pedestrian predictions. We will have completely mined the electromagnetic spectrum from rather short ma rays to rather long radio waves. We will have sent anned spacecraft to all of the planets and most of the lites in the solar system. We will have launched space-t into the Sun to do experimental stellar structure, nning perhaps – because of the low temperatures – with unspots. Hale would have appreciated that. I think it

possible that seventy-five years from now, we will ha launched subrelativistic spacecraft – travelling at about the speed of light – to the nearby stars. Among oth benefits, such missions would permit direct examination the interstellar medium and give us a longer baseline VLBI than many are thinking of today. We will have invent some new superlative to succeed 'very' – perha 'ultra'. The nature of pulsars, quasars and black hol should by then be well in hand, as well as the answers some of the deepest cosmological questions. It is ev possible that we will have opened up a regular communic tions channel with civilizations on planets of other sta and that the cutting edge of astronomy as well as ma other sciences will come from a kind of *Encyclopaed Galactica*, transmitted at very high bit rates to son immense array of radio telescopes.

But in reading the astronomy of seventy-five years ag I think it likely that, except for interstellar contact, the achievements, while interesting, will be considered rath old-fashioned astronomy, and that the real frontiers and t fundamental excitement of the science will be in areas th depend on new physics and new technology, which w can today at best dimly glimpse.

CHAPTER 22

THE QUEST FOR EXTRATERRESTRIAL INTELLIGENCE

* * *

Now the Sirens have a still more fatal weapon than their song, namely their silence ... Someone might possibly have escaped from their singing; but from their silence, certainly never.

FRANZ KAFKA,
Parables

OUGH ALL of our history we have pondered the stars and ed whether humanity is unique or if, somewhere else in dark of the night sky, there are other beings who emplate and wonder as we do, fellow thinkers in the ios. Such beings might view themselves and the universe rently. Somewhere else there might be very exotic ogies and technologies and societies. In a cosmic setting and old beyond ordinary human understanding, we are le lonely; and we ponder the ultimate significance, if of our tiny but exquisite blue planet. The search for terrestrial intelligence is the search for a generally otable cosmic context for the human species. In the est sense, the search for extraterrestrial intelligence is a ch for ourselves.

the last few years – in one-millionth the lifetime of our ies on this planet – we have achieved an extraordinary nological capability which enables us to seek out aginably distant civilizations even if they are no more nced than we. That capability is called radio astronomy involves single radio telescopes, collections or arrays of

radio telescopes, sensitive radio detectors, advanced co puters for processing received data, and the imagination a skill of dedicated scientists. Radio astronomy has in the l decade opened a new window on the physical universe may also, if we are wise enough to make the effort, cas profound light on the biological universe.

Some scientists working on the question of extraterrest intelligence, myself among them, have attempted to estim the number of advanced technical civilizations – defi operationally as societies capable of radio astronomy – the Milky Way Galaxy. Such estimates are little better th guesses. They require assigning numerical values to qua tities such as the numbers and ages of stars; the abunda of planetary systems and the likelihood of the origin of l which we know less well; and the probability of the evoluti of intelligent life and the lifetime of technical civilizatio about which we know very little indeed.

When we do the arithmetic, the sorts of numbers we co up with are, characteristically, around a million techni civilizations. A million civilizations is a breathtakingly la number, and it is exhilarating to imagine the diversity, li styles and commerce of those million worlds. But the Mil Way Galaxy contains some 250 billion stars, and even w a million civilizations, less than one star in 200,000 wou have a planet inhabited by an advanced civilization. Sin we have little idea which stars are likely candidates, we w have to examine a very large number of them. Su considerations suggest that the quest for extraterrestr intelligence may require a significant effort.

Despite claims about ancient astronauts and unidentifi flying objects, there is no firm evidence for past visitatio of the Earth by other civilizations (see Chapters 5 and We are restricted to remote signalling and, of the lon distance techniques available to our technology, radio is far the best. Radio telescopes are relatively inexpensiv

signals travel at the speed of light, faster than which
ng can go; and the use of radio for communication is
short-sighted or anthropocentric activity. Radio
sents a large part of the electromagnetic spectrum,
ny technical civilization anywhere in the Galaxy will
discovered radio early – just as in the last few centuries
ve explored the entire electromagnetic spectrum from
gamma rays to very long radio waves. Advanced
ations might very well use some other means of com-
cation with their peers. But if they wish to communicate
backward or emerging civilizations, there are only a few
us methods, the chief of which is radio.

e first serious attempt to listen for possible radio signals
other civilizations was carried out at the National
o Astronomy Observatory in Greenbank, West Vir-
, in 1959 and 1960. It was organized by Frank Drake,
at Cornell University, and was called Project Ozma,
the princess of the Land of Oz, a place very exotic,
distant and very difficult to reach. Drake examined
nearby stars, Epsilon Eridani and Tau Ceti, for a few
s with negative results. Positive results would have been
ishing because as we have seen, even rather optimistic
ates of the number of technical civilizations in the
xy imply that several hundred thousand stars must be
ined in order to achieve success by random stellar
tion.

ce Project Ozma, there have been six or eight other
programmes, all at a rather modest level, in the United
s, Canada and the Soviet Union. All results have been
tive. The total number of individual stars examined to
in this way is less than a thousand. We have performed
thing like one tenth of one percent of the required
t.

wever, there are signs that much more serious efforts
be mustered in the reasonably near future. All the

observing programmes to date have involved quite ti
amounts of time on large telescopes, or when large amou
of time have been committed, only very small radio te
scopes could be used. A comprehensive examination of t
problem was recently made by a NASA committee chair
by Philip Morrison of the Massachusetts Institute of Tec
nology. The committee identified a wide range of option
including new (and expensive) giant ground-based a
spaceborne radio telescopes. It also pointed out that maj
progress can be made at modest cost by the development
more sensitive radio receivers and of ingenious compute
ized data-processing systems. In the Soviet Union there is
state commission devoted to organizing a search for extr
terrestrial intelligence, and the large RATAN-600 rad
telescope in the Caucasus, recently completed, is devot
part-time to this effort. Hand in hand with the rece
spectacular advances in radio technology, there has been
dramatic increase in the scientific and public respectabili
of the entire subject of extraterrestrial life. A clear sign
the new attitude is the Viking missions to Mars, which a
to a significant extent dedicated to the search for life
another planet.

But along with the burgeoning dedication to a serio
search, a slightly negative note has emerged which is neve
theless very interesting. A few scientists have lately asked
curious question: If extraterrestrial intelligence is abunda
why have we not already seen its manifestations? Think
the advances by our own technical civilization in the pa
ten thousand years and imagine such advances continue
over millions or billions of years more. If only a tiny fracti
of advanced civilizations are millions or billions of yea
more advanced than ours, why have they not produce
artifacts, devices or even industrial pollution of such magn
tude that we would have detected it? Why have they n
restructured the entire Galaxy for their convenience?

ɔtics also ask why there is no clear evidence of extra-
rial visits to Earth. We have already launched slow
odest interstellar spacecraft. A society more advanced
ɔurs should be able to ply the spaces between the
onveniently if not effortlessly. Over millions of years
ɔcieties should have established colonies, which might
elves launch interstellar expeditions. Why are they not
The temptation is to deduce that there are at most a
lvanced extraterrestrial civilizations – either because
ically we are one of the first technical civilizations to
merged or because it is the fate of all such civilizations
troy themselves before they are much further along
we.

eems to me that such despair is quite premature. All
arguments depend on our correctly surmising the
ions of beings far more advanced than ourselves, and
examined more closely I think these arguments reveal
ge of interesting human conceits. Why do we expect
t will be easy to recognize the manifestations of very
ced civilizations? Is our situation not closer to that of
ers of an isolated society in the Amazon basin, say,
ack the tools to detect the powerful international
and television traffic that is all around them? Also,
s a wide range of incompletely understood phenomena
onomy. Might the modulation of pulsars or the energy
of quasars, for example, have a technological origin?
rhaps there is a galactic ethic of noninterference with
vard or emerging civilizations. Perhaps there is a
g time before contact is considered appropriate, so as
e us a fair opportunity to destroy ourselves first, if
e so inclined. Perhaps all societies significantly more
ced than our own have achieved an effective personal
rtality and lose the motivation for interstellar galli-
g, which may, for all we know, be a typical urge only
olescent civilizations. Perhaps mature civilizations do

not wish to pollute the cosmos. There is a very long list o such 'perhapses', few of which we are in a position t evaluate with any degree of assurance.

The question of extraterrestrial civilizations seems to m entirely open. Personally, I think it far more difficult t understand a universe in which we are the only technologica civilization, or one of a very few, than to conceive of cosmos brimming over with intelligent life. Many aspects o the problem are, fortunately, amenable to experimenta verification. We can search for planets of other stars, see simple forms of life on such nearby planets as Mars, an perform more extensive laboratory studies on the chemistr of the origin of life. We can investigate more deepl the evolution of organisms and societies. The problem cries out for a long-term, open-minded, systemati search, with nature as the only arbiter of what is or is no likely.

If there are a million technical civilizations in the Milk Way Galaxy, the average separation between civilizations i about 300 light-years. Since a light-year is the distance tha light travels in one year (a little under 6 trillion miles), thi implies that the one-way transit time for an interstella communication from the nearest civilization is some 30 years. The time for a query and a response would be 60 years. This is the reason that interstellar dialogues are muc less likely – particularly around the time of first contact – than interstellar monologues. At first sight, it seems remark ably selfless that a civilization might broadcast radi messages with no hope of knowing, at least in the immediat future, whether they have been received and what th response to them might be. But human beings often perform very similar actions as, for example, burying time capsule to be recovered by future generations, or even writing books composing music and creating art intended for posterity. A civilization that had been aided by the receipt of such

essage in its past might wish similarly to benefit other merging technical societies.

For a radio search programme to succeed, the Earth must e among the intended beneficiaries. If the transmitting vilization were only slightly more advanced than we are, it ould possess ample radio power for interstellar com- unication – so much, perhaps, that the broadcasting could delegated to relatively small groups of radio hobbyists nd partisans of primitive civilizations. If an entire planetary overnment or an alliance of worlds carried out the project, ne broadcasters could transmit to a very large number of ars, so large that a message is likely to be beamed our ay, even though there may be no reason to pay special tention to our region of the sky.

It is easy to see that communication is possible, even ithout any previous agreement or contact between trans- itting and receiving civilizations. There is no difficulty envisioning an interstellar radio message that unam- iguously arises from intelligent life. A modulated signal eep, beep-beep, beep-beep-beep ...) comprising the umbers 1, 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31 – the rst dozen prime numbers – could have only a biological rigin. No prior agreement between civilizations and no recautions against Earth chauvinism are required to make his clear.

Such a message would be an announcement, or beacon, gnal, indicating the presence of an advanced civilization it communicating very little about its nature. The beacon gnal might also note a particular frequency where the main essage is to be found, or might indicate that the principal essage can be found at higher time resolution at the equency of the beacon signal. The communication of quite mplex information is not very difficult, even for civiliza- ons with extremely different biologies and social con- ntions. Arithmetical statements can be transmitted, some

true and some false, each followed by an appropriate cod word (in dahs and dits, for example), which would transi the ideas of true and false, concepts that many peo might guess would be extremely difficult to communicate such a context.

But by far the most promising method is to send pictur A repeated message that is the product of two pri numbers is clearly to be decoded as a two-dimensio array, or raster – that is, a picture. The product of thr prime numbers might be a three-dimensional still picture one frame of a two-dimensional motion picture. As example of such a message, consider an array of zeros a ones which could be long and short beeps or tones on tw adjacent frequencies, or tones of different amplitudes, even signals with different radio polarizations. In 1974 su a message was transmitted to space from the 305-met antenna at the Arecibo Observatory in Puerto Rico, whi Cornell University runs for the National Science Found tion. The occasion was a ceremony marking the resurfaci of the Arecibo dish, the largest radio/radar telescope on t planet Earth. The signal was sent to a collection of sta called M13, a globular cluster comprising about a milli separate suns which happened to be overhead at the tir of the ceremony. Since M13 is 24,000 light-years awa the message will take 24,000 years to arrive there. If a responsive crature is listening, it will be 48,000 years befo we receive a reply. The Arecibo message was clearly intend not as a serious attempt at interstellar communication, b rather as an indication of the remarkable advances terrestrial radio technology.

The decoded message says something like this: 'Here how we count from one to ten. Here are the atom numbers of five chemical elements – hydrogen, carbo nitrogen, oxygen and phosphorus – that we think a interesting or important. Here are some ways to put the

ms together: the molecules adenine, thymine, guanine
l cytosine, and a chain composed of alternating sugars
l phosphates. These molecular building blocks are in turn
t together to form a long molecule of DNA comprising
ut four billion links in the chain. The molecule is a
ble helix. In some way this molecule is important for the
nsy-looking creature at the centre of the message. That
ture is 14 radio wavelengths, or about 176 centimetres,
h. There are about four billion of these creatures on the
d planet from our star. There are nine planets altogether
our little ones on the inside, four big ones towards the
side and one little one at the extremity. This message is
ught to you courtesy of a radio telescope 2,430 wave-
gths, or 306 metres, in diameter. Yours truly.'

With many similar pictorial messages, each consistent
h and corroborating the others, it is very likely that
ost unambiguous interstellar radio communication
ld be achieved even between two civilizations that have
er met. Our immediate objective is not to send such
sages because we are very young and backward; we wish
isten.

The detection of intelligent radio signals from the depths
space would approach in an experimental and scientifi-
y rigorous manner many of the most profound questions
t have concerned scientists and philosophers since pre-
oric times. Such a signal would indicate that the origin
ife is not an extraordinary, difficult or unlikely event. It
ld imply that, given billions of years for natural
ction, simple forms of life evolve generally into complex
intelligent forms, as on Earth; and that such intelligent
ns commonly produce an advanced technology, as has
occurred here. But it is not likely that the transmissions
receive will be from a society at our own level of
nological advance. A society only a little more backward
n ours will not have radio astronomy at all. The most

likely case is that the message will be from a civilizatio in our technological future. Thus, even before we de such a message, we will have gained an invaluable pie knowledge: that it is possible to avoid the dangers o period through which we are now passing.

There are some who look on our global problems on Earth – at our vast national antagonisms, our nuc arsenals, our growing populations, the disparity betw the poor and the affluent, shortages of food and resou and our inadvertent alterations of the natural environme and conclude that we live in a system that has sudd become unstable, a system that is destined soon to colla There are others who believe that our problems are solu that humanity is still in its childhood, that one day s we will grow up. The receipt of a single message f space would show that it is possible to live through s technological adolescence: the transmitting civilizat after all, has survived. Such knowledge, it seems to me, m be worth a great price.

Another likely consequence of an interstellar message strengthening of the bonds that join all human and o beings on our planet. The sure lesson of evolution is organisms elsewhere must have separate evolutionary p ways; that their chemistry and biology and very likely t social organizations will be profoundly dissimilar to a thing on Earth. We may well be able to communicate w them because we share a common universe - because laws of physics and chemistry and the regularities astronomy are universal. But they may always be, in deepest sense, different. And in the face of this differe the animosities that divide the peoples of the Earth wither. The differences among human beings of sepa races and nationalities, religions and sexes, are likely to insignificant compared to the differences between all hu and all extraterrestrial intelligent beings.

the message comes by radio, both transmitting and iving civilizations will have in common at least a wledge of radiophysics. The commonality of the physical nces is the reason that many scientists expect the sages from extraterrestrial civilizations to be decodable robably in a slow and halting manner, but unam- iously nevertheless. No one is wise enough to predict etail what the consequences of such a decoding will be, use no one is wise enough to understand beforehand t the nature of the message will be. Since the trans- sion is likely to be from a civilization far in advance ur own, stunning insights are possible in the physical, logical and social sciences, in the novel perspective of a e different kind of intelligence. But decoding will prob- be a task of years and decades.

ome have worried that a message from an advanced ety might make us lose faith in our own, might deprive of the initiative to make new discoveries if it seemed others had made those discoveries already, or might e other negative consequences. This is rather like a lent dropping out of school because his teachers and text- ks are more learned than he is. We are free to ignore interstellar message if we find it offensive. If we choose to respond, there is no way for the transmitting civiliza- to determine that its message was received and under- od on the tiny distant planet Earth. The translation of a io message from the depths of space, about which we can as slow and cautious as we wish, seems to pose few gers to mankind; instead, it holds the greatest promise both practical and philosophical benefits.

n particular, it is possible that among the first contents of h a message may be detailed prescriptions for the idance of technological disaster, for a passage through lescence to maturity. Perhaps the transmissions from anced civilizations will describe which pathways of

cultural evolution are likely to lead to the stability
longevity of an intelligent species, and which other pa
lead to stagnation or degeneration or disaster. There is
course, no guarantee that such would be the contents
an interstellar message, but it would be foolhardy to o
look the possibility. Perhaps there are straightforw
solutions, still undiscovered on Earth, to problems of f
shortages, population growth, energy supplies, dwindl
resources, pollution and war.

While there will surely be differences among civilizatio
there may well be laws of development of civilizations wh
cannot be glimpsed until information is available ab
the evolution of many civilizations. Because of our isolat
from the rest of the cosmos, we have information on
evolution of only one civilization – our own. And the m
important aspect of that evolution – the future – rema
closed to us. Perhaps it is not likely, but it is certai
possible that the future of human civilization depends on
receipt and decoding of interstellar messages from ex
terrestrial civilizations.

And what if we make a long-term, dedicated search
extraterrestrial intelligence and fail? Even then we surely
not have wasted our time. We will have developed
important technology, with applications to many ot
aspects of our own civilization. We will have added grea
to our knowledge of the physical universe. And we will h
calibrated something of the importance and uniqueness
our species, our civilization and our planet. For if intellig
life is scarce or absent elsewhere, we will have learn
something significant about the rarity and value of
culture and our biological patrimony, painstakingly
tracted over 4.6 billion years of tortuous evolution
history. Such a finding will stress, as perhaps nothing e
can, our responsibilities to the dangers of our time: beca
the most likely explanation of negative results, afte

prehensive and resourceful search, is that societies monly destroy themselves before they are advanced ugh to establish a high-power radio-transmitting service. n interesting sense, the organization of a search for rstellar radio messages, quite apart from the outcome, is y to have a cohesive and constructive influence on the le of the human predicament.

ut we will not know the outcome of such a search, much the contents of messages from interstellar civilizations, if lo not make a serious effort to listen for signals. It may hat civilizations are divided into two great classes: those make such an effort, achieve contact and become new nbers of a loosely tied federation of galactic com- nities, and those that cannot or choose not to make such effort, or who lack the imagination to try, and who in sequence soon decay and vanish.

is difficult to think of another enterprise within our ability and at a relatively modest cost that holds as much mise for the future of humanity.

PART V

ULTIMATE QUESTIONS

CHAPTER 23

A SUNDAY SERMON

* * *

Extinguished theologians lie about the cradle of every science as the strangled snakes beside [the cradle] of Hercules.

T. H. HUXLEY [1860]

We have seen the highest circle of spiralling powers. We have named this circle God. We might have given it any other name we wished: Abyss, Mystery, Absolute Darkness, Absolute Light, Matter, Spirit, Ultimate Hope, Ultimate Despair, Silence.

NIKOS KAZANTZAKIS (1948)

E DAYS, I often find myself giving scientific talks to ular audiences. Sometimes I am asked to discuss etary exploration and the nature of the other planets; etimes, the origin of life or intelligence on Earth; some-s, the search for life elsewhere; and sometimes, the grand ological perspective. Since I have, more or less, heard talks before, the question period holds my greatest est. It reveals the attitudes and concerns of people. The common questions asked are on unidentified flying cts and ancient astronauts – what I believe are thinly ised religious queries. Almost as common – particu- after a lecture in which I discuss the evolution of life telligence – is: 'Do you believe in God?' Because the l 'God' means many things to many people, I frequently by asking what the questioner means by 'God'. To my rise, this response is often considered puzzling or pected: 'Oh, you know, *God*. Everyone knows who God Or 'Well, kind of a force that is stronger than we are that exists everywhere in the universe.' There are a

number of such forces. One of them is called gravity, is not often identified with God. And not everyone know what is meant by 'God'. The concept covers a range of ideas. Some people think of God as an outs light-skinned male with a long white beard, sitting throne somewhere up there in the sky, busily tallying th of every sparrow. Others – for example, Baruch Spinoz Albert Einstein – considered God to be essentially the total of the physical laws which describe the universe. not know of any compelling evidence for anthropomo patriarchs controlling human destiny from some hi celestial vantage point, but it would be madness to the existence of physical laws. Whether we believe in depends very much on what we mean by God.

In the history of the world there have been, probably of thousands of different religions. There is a intentioned pious belief that they are all fundamen identical. In terms of an underlying psychological reson there may indeed be important similarities at the cor many religions, but in the details of ritual and doc and the *apologias* considered to be authenticating diversity of organized religions is striking. Human reli are mutually exclusive on such fundamental issues as god versus many; the origin of evil; reincarnation; idol magic and witchcraft; the role of women; dietary scriptions; rites of passage; ritual sacrifice; direc mediated access to deities; slavery; intolerance of religions; and the community of beings to whom sp ethical considerations are due. We do no service to rel in general or to any doctrine in particular if we paper these differences. Instead, I believe we should understan world views from which differing religions derive and se understand what human needs are fulfilled by those ferences.

Bertrand Russell once told of being arrested becau

cefully protested Britain's entry into World War I. The
r asked – then a routine question for new arrivals –
sell's religion. Russell replied, 'Agnostic', which he was
ed to spell. The jailer smiled benignly, shook his head,
said, 'There's many different religions, but I suppose we
worship the same God.' Russell commented that the
ark cheered him for weeks. And there may not have
n much else to cheer him in that prison, although he did
nage to write the entire *Introduction to Mathematical*
losophy and started reading for his work *The Analysis of*
nd within its confines.

Many of the people who ask whether I believe in God are
uesting reassurance that their particular belief system,
tever it is, is consistent with modern scientific know-
ge. Religion has been scarred in its confrontation with
nce, and many people – but by no means all – are
ctant to accept a body of theological belief that is too
iously in conflict with what else we know. Apollo 8
omplished the first manned lunar circumnavigation. In a
e or less spontaneous gesture, the Apollo 8 astronauts
d from the first verse of the Book of Genesis, in part, I
eve, to reassure the taxpayers back in the United States
there were no real inconsistencies between conventional
gious outlooks and a manned flight to the Moon.
hodox Muslims, on the other hand, were outraged after
llo 11 astronauts accomplished the first manned lunar
ding, because the Moon has a special and sacred signifi-
ce in Islam. In a different religious context, after Yuri
garin's first orbital flight, Nikita Khrushchev, the chair-
n of the Council of Ministers of the USSR, noted that
garin had stumbled on no gods or angels up there –
is, Khrushchev reassured his audience that manned
ital flight was not inconsistent with its beliefs.

n the 1950s a Soviet technical journal called *Voprosy*
sofi (Problems in Philosophy) published an article that

argued – very unconvincingly, it seemed to me – dialectical materialism required there to be life on e planet. Some time later an agonized official reb appeared, decoupling dialectical materialism from biology. A clear prediction in an area undergoing vigo study permits doctrines to be subject to disproof. The posture a bureaucratic religion wished to find itself i vulnerability to disproof, where an experiment can be formed on which the religion stands or falls. And so fact that life has not been found on the Moon has left foundations of dialectical materialism unshaken. Doctr that make no predictions are less compelling than th which make correct predictions; they are in turn m successful than doctrines that make false predictions.

But not always. One prominent American religion c fidently predicted that the world would end in 1914. W 1914 has come and gone, and – while the events of that were certainly of some importance – the world does no least so far as I can see, seem to have ended. There at least three responses that an organized religion can m in the face of such a failed and fundamental prophecy. T could have said, 'Oh, did we say "1914"? So sorry, meant "2014". A slight error in calculation. Hope weren't inconvenienced in any way.' But they did not. T could have said, 'Well, the world *would* have ended, ex we prayed very hard and interceded with God so He spa the Earth.' But they did not. Instead, they did someth much more ingenious. They announced that the world in fact ended in 1914, and if the rest of us hadn't noti that was our lookout. It is astonishing in the face of s transparent evasions that this religion has any adheren all. But religions are tough. Either they make no content which are subject to disproof or they quickly rede doctrine after disproof. The fact that religions can b shamelessly dishonest, so contemptuous of the intellig

heir adherents, and still flourish does not speak very
! for the toughmindedness of the believers. But it does
icate, if a demonstration were needed, that near the core
he religious experience is something remarkably resistant
rational inquiry.

Andrew Dickson White was the intellectual guiding light,
nder and first president of Cornell University. He was
the author of an extraordinary book called *The Warfare
Science with Theology in Christendom*, considered so
ndalous at the time it was published that his co-author
uested his name omitted. White was a man of substantial
gious feeling.* But he outlined the long and painful
ory of erroneous claims which religions had made about
nature of the world, and how, when people directly
estigated the nature of the world and discovered it to be
erent from doctrinal contentions, such people were
secuted and their ideas suppressed. The aged Galileo was
atened by the Catholic hierarchy with torture because he
claimed the Earth to move. Spinoza was excommuni-
ed by the Jewish hierarchy, and there is hardly an
anized religion with a firm body of doctrine which has
at one time or another persecuted people for the crime of
n inquiry. Cornell's own devotion to free and non-
arian inquiry was considered so objectionable in the last
rter of the nineteenth century that ministers advised high
ool graduates that it was better to receive no college
cation than to attend so impious an institution. Indeed,
Sage Chapel was constructed in part to placate the
us – although, I am glad to say, it has from time to
e made serious efforts at open-minded ecumenicism.

White seems also to have been responsible for the exemplary custom
ot awarding honorary doctoral degrees at Cornell University: he was
erned about a potential abuse, that honorary degrees would be traded
inancial gifts and bequests. White was a man of strong and courageous
al standards.

Many of the controversies which White describes about origins. It used to be believed that every event i world – the opening of a morning glory, let us say – due to direct microintervention by the Deity. The fl was unable to open by itself. God had to say, 'Hey, flo open'. The application of this idea to human affairs often had desultory social consequences. For one thi seems to imply that we are not responsible for our act If the play of the world is produced and directed b omnipotent and omniscient God, does it not follow every evil that is perpetrated is God's doing? I know idea is an embarrassment in the West, and attempts to a it include the contention that what seems to be evil is r part of the Divine Plan, too complex for us to fathon that God chose to cloud his own vision about the caus skein when he set out to make the world. There is n ing utterly impossible about these philosophical re attempts, but they do seem to have very much the chara of propping up a teetering ontological structure.* addition, the idea of microintervention in the affairs o world has been used to support the established so political and economic conventions. There was, for exan the idea of a 'Divine Right of Kings', seriously argue philosophers such as Thomas Hobbes. If you had rev tionary thoughts directed, let us say, towards George

* Many statements about God are confidently made by theologia grounds that today at least sound specious. Thomas Aquinas claim prove that God cannot make another God, or commit suicide, or m man without a soul, or even make a triangle whose interior angl not equal 180 degrees. But Bolyai and Lobachevsky were able to accon this last feat (on a curved surface) in the nineteenth century, and were not even approximately gods. It is a curious concept this, omnipotent God with a long list of things he is forbidden to do b fiat of the theologians.

were guilty of blasphemy and impiety, religious crimes, vell as such more commonplace political crimes as son.

here are many legitimate scientific issues relating to ns and ends: What is the origin of the human species? re did plants and animals come from? how did life arise? Earth, the planets, the Sun, the stars? Does the universe an origin, and if so, what? And finally, a still more damental and exotic question, which many scientists ld say is essentially untestable and therefore meaning- Why are the laws of nature the way they are? The idea a God or gods is necessary to effect one or more of e origins has been under repeated attack over the last thousand years. Because we know something about otropism and plant hormones, we can understand the ing of the morning glory independent of divine micro- rvention. It is the same for the entire skein of causality to the origin of the universe. As we learn more and e about the universe, there seems less and less for God o. Aristotle's view was of God as an unmoved prime er, a *roi fainéant*, a do-nothing king who establishes the erse in the first place and then sits back and watches the cate, intertwined chains of causality course down ugh the ages. But this seems abstract and removed from yday experience. It is a little unsettling and pricks at an conceits.

umans seem to have a natural abhorrence of infinite ession of causes, and this distaste is at the root of the t famous and most effective demonstrations of the ence of God by Aristotle and Thomas Aquinas. But e thinkers lived before the infinite series was a mathe- cal commonplace. If the differential and integral cal- s or transfinite arithmetic had been invented in Greece ne fifth century B.C., and not subsequently suppressed, history of religion in the West might have been very

different – or at any rate we would have seen less of
pretension that theological doctrine can be convincin
demonstrated by rational argument to those who rej
alleged divine revelation, as Aquinas attempted in
Summa Contra Gentiles.

When Newton explained the motion of the planets by
universal theory of gravitation, it no longer was necessa
for angels to push and pummel the planets about. Wh
Pierre Simon, the Marquis de Laplace, proposed to expla
the origin of the solar system – although not the origin
matter – in terms of physical laws as well, even the necess
for a god involved in the origins of things seemed p
foundly challenged. Laplace is said to have presented
edition of his seminal mathematical work *Mécanique céle*
to Napoleon aboard ship in the Mediterranean during
Napoleonic expedition to Egypt, 1798 to 1799. A few da
later, so the story goes, Napoleon complained to Lapla
that he had found no mention of God in the text.* Laplac
response has been recorded: 'Sire, I have no need of th
hypothesis.' The idea of God as a hypothesis rather than
an obvious truth is by and large a modern idea in the Wes
although it was certainly discussed seriously and wryly
the Ionian philosophers of 2,400 years ago.

It is often considered that at least the origin of the unive

* It is a charming notion that Napoleon actually spent his days abo
ship perusing the highly mathematical *Mécanique céleste*. But he
seriously interested in science and made an earnest attempt to survey
latest findings (see *The Society of Arcueil: A View of French Science at
Time of Napoleon I* by Maurice Crosland, Cambridge, Harvard Univers
Press, 1967). Napoleon did not pretend to read all of the *Mécani
céleste* and wryly wrote to Laplace on another occasion, 'The first
months which I can spare will be employed in reading it.' But he a
remarked, on another of Laplace's books, 'Your works contribute to
glory of the nation. The progress and perfection of mathematics are lin
closely with the prosperity of the state.'

uires a God – indeed, an Aristotelian idea.* This is a point rth looking at in a little more detail. First of all, it is fectly possible that the universe is infinitely old and refore requires no Creator. This is consistent with existing owledge of cosmology, which permits an oscillating verse in which the events since the Big Bang are merely latest incarnation in an infinite series of creations and tructions of the universe. But secondly, let us consider idea of a universe created somehow from nothing by d. The question naturally arises – and many ten-year-olds ntaneously think of it before being discouraged by their ers – where does God come from? If we answer that God nfinitely old or present simultaneously in all epochs, we ve solved nothing, except perhaps verbally. We have rely postponed by one step coming to grips with the blem. A universe that is infinitely old and a God that is nitely old are, I think, equally deep mysteries. It is not dily apparent why one should be considered more reliably ablished than the other. Spinoza might have said that the possibilities are not really different ideas at all.

think it is wise, when coming face to face with such found mysteries, to feel a little humility. The idea that entists or theologians, with our present still puny under-nding of this vast and awesome cosmos, can comprehend origins of the universe is only a little less silly than the a the Mesopotamian astronomers of 3,000 years ago – m whom the ancient Hebrews borrowed, during the bylonian captivity, the cosmological accounts in the first pter of Genesis – could have understood the origins of universe. We simply do not know. The Hindu holy book,

* However, from astronomical arguments Aristotle concluded that there e several dozen unmoved prime movers in the universe. Aristotelian uments for a prime mover would seem to have polytheistic consequences might be considered dangerous by contemporary Western theologians.

the Rig Veda (X:129), has a much more realistic view of matter:

> Who knows for certain? Who shall here declare it?
> Whence was it born, whence came creation?
> The gods are later than this world's formation;
> Who then can know the origins of the world?
> None knows whence creation arose;
> And whether he has or has not made it;
> He who surveys it from the lofty skies,
> Only he knows – or perhaps he knows not.

But the times we live in are very interesting or
Questions of origins, including some questions relating
the origin of the universe, may in the next few decades
amenable to experimental inquiry. There is no conceiva
answer to the grand cosmological questions which will
resonate with the religious sensibilities of human beings.
there is a chance that the answers will discomfit a gr
many bureaucratic and doctrinal religions. The idea
religion as a body of belief, immune to criticism, fi
forever by some founder is, I think, a prescription for
long-term decay of the religion, especially lately.
questions of origins and ends, the religious and the scient
sensibilities have much the same objectives. Human bei
are built in such a way that we passionately wish to answ
these questions – perhaps because of the mystery of our o
individual origins. But our contemporary scientific insigh
while limited, are much deeper than those of our Babylon
predecessors of 1,000 B.C. Religions unwilling to acco
modate to change, both scientific and social, are, I belie
doomed. A body of belief cannot be alive and releva
vibrant and growing, unless it is responsive to the m
serious criticism that can be mustered against it.

The First Amendment to the United States Constitut

ourages a diversity of religions but does not prohibit
icism of religion. In fact it protects and encourages
icism of religion. Religions ought to be subject to at least
same degree of scepticism as, for example, contentions
ut UFO visitations or Velikovskian catastrophism. I
ık it is healthy for the religions themselves to foster
pticism about the fundamental underpinnings of their
dential bases. There is no question that religion provides
olace and support, a bulwark in time of emotional need,
l can serve extremely useful social roles. But it by no
ans follows that religion should be immune from testing,
m critical scrutiny, from scepticism. It is striking how
le sceptical discussion of religion there is in the nation
t Tom Paine, the author of *The Age of Reason*, helped to
nd. I hold that belief systems that cannot survive scrutiny
probably not worth having. Those that do survive
utiny probably have at least important kernels of truth
hin them.

Religion used to provide a generally accepted understand-
of our place in the universe. That surely has been one
he major objectives of myth and legend, philosophy and
gion, as long as there have been human beings. But the
tual confrontation of differing religions and of religion
h science has eroded those traditional views, at least in
minds of many.* The way to find out about our place in

This subject is rich in irony. Augustine was born in Africa in 354 A.D.
in his early years was a Manichean, an adherent of a dualistic view
he universe in which good and evil are in conflict on roughly equal
ns, and which was later condemned as a 'heresy' by Christian orthodoxy.
possibility that all was not right with Manicheanism occurred to
gustine when he was studying its astronomy. He discovered that even
leading figures in the faith could not justify its murky astronomical
.ons. This contradiction between theology and science on matters
onomical was the initial impetus moving him towards Catholicism,
religion of his mother, which in later centuries persecuted scientists
h as Galileo for trying to improve our understanding of astronomy.

the universe is by examining the universe and by examini ourselves – without preconceptions, with as unbiased a mi as we can muster. We cannot begin with an entirely cle slate, since we arrive at this problem with predispositions hereditary and environmental origin; but, after understan ing such built-in biases, is it not possible to pry insights fr nature?

Proponents of doctrinal religions – ones in which particular body of belief is prized and infidels scorned will be threatened by the courageous pursuit of knowled We hear from such people that it may be dangerous probe too deeply. Many people have inherited their religi like their eye colour: they consider it not a thing to thi very deeply about, and in any case beyond our contr But those with a set of beliefs they profess to feel deep about, which they have selected without an unbiased sifti through the facts and the alternatives, will feel unco fortably challenged by searching questions. Anger at quer about our beliefs is the body's warning signal: here l unexamined and probably dangerous doctrinal baggage

Christianus Huygens wrote a remarkable book arou 1670 in which bold and prescient speculations were ma about the nature of the other planets in the solar syste Huygens was well aware that there were those who held su speculations and his astronomical observations objectio able: 'But perhaps they'll say,' Huygens mused, 'it does n become us to be so curious and inquisitive in these Thin which the Supreme Creator seems to have kept for his ow Knowledge: For since he has not been pleased to make a

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Augustine later became Saint Augustine, one of the major intellect figures in the history of the Roman Catholic church, and his mot became Saint Monica, after whom a suburb of Los Angeles is nam Bertrand Russell wondered what Augustine's view of the conflict betw astronomy and theology would have been had he lived in the time Galileo.

ıer Discovery or Revelation of them, it seems little better
ı presumption to make any inquiry into that which he
thought fit to hide. But these Gentlemen must be told,'
gens then thundered, 'that they take too much upon
ıselves when they pretend to appoint how far and no
ıer Men shall go in their Searches, and to set bounds to
r Mens Industry; as if they knew the Marks that God
placed to Knowledge: or as if Men were able to pass
e Marks. If our Forefathers had been at this rate
pulous, we might have been ignorant still of the Magni-
and Figure of the Earth, or that there was such a
e as America.'

we look at the universe in the large, we find something
nishing. First of all, we find a universe that is ex-
ionally beautiful, intricately and subtly constructed.
ther our appreciation of the universe is because we are
rt of that universe – whether, no matter how the universe
put together, we would have found it beautiful – is a
position to which I do not pretend to have an answer.
there is no question that the elegance of the universe
ıe of its most remarkable properties. At the same time,
e is no question that there are cataclysms and catas-
hes occurring regularly in the universe and on the most
some scale. There are, for example, quasar explosions
h probably decimate the nuclei of galaxies. It seems
y that every time a quasar explodes, more than a million
lds are obliterated and countless forms of life, some of
ı intelligent, are utterly destroyed. This is not the
itional benign universe of conventional religiosity in the
t, constructed for the benefit of living and especially of
an beings. Indeed, the very scale of the universe – more
a hundred billion galaxies, each containing more than
undred billion stars – speaks to us of the inconse-
ıtiality of human events in the cosmic context. We see
iverse simultaneously very beautiful and very violent.

We see a universe that does not exclude a tradition
Western or Eastern god, but that does not require o
either.

My deeply held belief is that if a god of anything like t
traditional sort exists, our curiosity and intelligence a
provided by such a god. We would be unappreciative
those gifts (as well as unable to take such a course
action) if we suppressed our passion to explore the univer
and ourselves. On the other hand, if such a traditional g
does not exist, our curiosity and our intelligence are t
essential tools for managing our survival. In either case, t
enterprise of knowledge is consistent with both science a
religion, and is essential for the welfare of the human speci

CHAPTER 24

GOTT AND THE TURTLES

* * *

Now entertain conjecture of a time
When creeping murmur and the poring dark
Fills the wide vessel of the universe.

WILLIAM SHAKESPEARE,
Henry V, Act IV, Prologue

THE EARLIEST myths and legends of our species, there is a nmon and understandable view of the cosmos: it is hropocentric. There were gods, to be sure. But the gods d feelings and weaknesses and were very human. Their haviour was seen as capricious. They could be propitiated sacrifice and prayer. They intervened regularly in human airs. Various factions of gods supported opposing sides in man warfare. The *Odyssey* expresses a generally held view t it is wise to be kind to strangers: they may be gods in guise. Gods mate with humans, and the offspring are erally indistinguishable, at least in appearance, from ople. The gods live on mountains or in the sky, or in ne subterranean or submarine realm – at any rate, far off. was difficult unambiguously to come upon a god, and so was hard to check a story told about the gods. Sometimes *ir* actions were controlled by more powerful beings yet, as Fates controlled the Olympian gods. The nature of the iverse as a whole, its origin and fate, were not considered ll understood. In the Vedic myths, doubt is raised not ly about whether the gods created the world but even ut whether the gods know who *did* create it. Hesiod in his osmogony' says that the universe was created from (or

maybe by) Chaos – perhaps only a metaphor for t
difficulty of the problem.

Some ancient Asian cosmological views are close to t
idea of an infinite regression of causes, as exemplified
the following apocryphal story: A Western traveller e
countering an Oriental philosopher asks him to descri
the nature of the world:

'It is a great ball resting on the flat back of the wor
turtle.'

'Ah yes, but what does the world turtle stand on?'

'On the back of a still larger turtle.'

'Yes, but what does he stand on?'

'A very perceptive question. But it's no use, mister; it
turtles all the way down.'

We now know that we live on a tiny dust mote in a
immense and humbling universe. The gods, if they exist, n
longer intervene daily in human affairs. We do not live in a
anthropocentric universe. And the nature, origin and fate
the cosmos seem to be mysteries far more profound tha
they were perceived to be by our remote ancestors.

But the situation is once again changing. Cosmology, th
study of the universe as a whole, is becoming an exper
mental science. Information obtained by optical and radi
telescopes on the ground, by ultraviolet and X-ray telescope
in Earth orbit, by the measurement of nuclear reactions i
laboratories, and by determinations of the abundance
chemical elements in meteorites, is shrinking the arena
permissible cosmological hypotheses; and it is not too muc
to expect that we will soon have firm observational answe
to questions once considered the exclusive preserve
philosophical and theological speculation.

This observational revolution began from an unlike
source. In the second decade of this century there was – a
there still is – in Flagstaff, Arizona, an astronomical facili
called the Lowell Observatory, established by none oth

Percival Lowell, for whom the search for life on other
ets was a consuming passion. It was he who popularized
promoted the idea that Mars was crisscrossed with
ls, which he believed to be the artifacts of a race of
gs enamoured of hydraulic engineering. We now know
the canals do not exist at all. They apparently were
product of wishful thinking and the limitations of
rving through the Earth's murky atmosphere.

mong his other interests, Lowell was concerned with the
l nebulae – exquisite pinwheel-shaped luminous objects
e sky, which we now know to be distant collections of
dreds of billions of individual stars, like the Milky Way
xy of which our Sun is a part. But at that time there
no way to determine the distance to these nebulae,
Lowell was interested in an alternative hypothesis – that
spiral nebulae were not enormous, distant, multistellar
ties, but rather smaller, closer objects which were the
y stages of the condensation of an individual star out of
interstellar gas and dust. As such gas clouds contract
er their self-gravitation, the conservation of angular
nentum requires that they speed up to rapid rotation
shrink to a thin disc. Rapid rotation can be detected
onomically by spectroscopy, letting light from a distant
ct pass consecutively through a telescope, a narrow slit
a glass prism or other device which spreads white light
into a rainbow of colours. The spectrum of starlight
tains bright and dark lines here and there in the rainbow,
ges of the slit of the spectrometer. An example is the
ht yellow lines emitted by sodium, apparent as we throw
all piece of sodium into a flame. Material made of many
erent chemical elements will show many different
tral lines. The displacement of these spectral lines from
r usual wavelengths when the light source is at rest gives
nformation on the velocity of the source towards and
y from us – a phenomenon called the Doppler effect

and familiar to us, in the physics of sound, as the increa or decrease in the pitch of an automobile horn as the rapidly approaches or recedes.

Lowell is thought to have asked a young assistant, V. Slipher, to check the larger spiral nebulae to determi whether one side showed spectral lines shifted towards t red and the other towards the blue, from which it would possible to deduce the speed of rotation of the nebu Slipher investigated the spectra of the nearby spiral nebul but found to his amazement that almost all of them show a red shift, with virtually no sign of blue shifts an where in them. He had found not rotation, but recessio It was as if all the spiral nebulae were retreating fro *us*.

A much more extensive set of observations was obtain in the 1920s at the Mount Wilson Observatory by Edw Hubbell and Milton Humason. Hubbell and Humas developed a method of determining the distance to the spi nebulae; it became apparent that they were not condensi gas clouds relatively nearby in the Milky Way Galaxy, b themselves great galaxies millions or more light-years awa To their amazement, they also found that the more dista the galaxy, the faster it was receding from us. Since it unlikely that there is anything special about our position the cosmos, this is best understood in terms of a gene expansion of the universe; all galaxies recede from all othe so that an astronomer on any galaxy would observe all oth galaxies apparently retreating.

If we extrapolate such a mutual recession back into t past, we find that there was a time – perhaps 15 billion 20 billion years ago – when all of the galaxies must ha been 'touching'; that is, confined to an extremely sm volume of space. Matter in its present form could not survi such astonishing compressions. The very earliest stages that expanding universe must have been dominated

ıtion rather than matter. It is now conventional to talk
ıis time as the Big Bang.

ıree kinds of explanation have been offered for this
nsion of the universe: the Steady State, Big Bang and
ılating Universe cosmologies. In the Steady State hypo-
s, the galaxies recede from one another, the more distant
xies moving with very high apparent velocities, their
shifted by the Doppler effect to longer and longer wave-
ths. There will be a distance at which a galaxy will be
ing so fast that it passes over what is called its event
zon and, from our vantage point, disappears. There is a
ınce so great that, in an expanding universe, there is no
ıce of getting information from beyond it. As time goes
if nothing else intervenes, more and more galaxies will
ppear over the edge. But in the Steady State cosmology,
natter lost over the edge is exactly compensated for by
matter continuously created everywhere, matter that
tually condenses into new galaxies. With the rate of
ppearance of galaxies over the event horizon just
nced by the creation of new galaxies, the universe looks
e or less identical from every place and in every epoch.
he Steady State cosmology there is no Big Bang; one
dred billion years ago the universe would have looked
the same, and one hundred billion years from now, like-
. But where does the new matter come from? How can
ter be created from nothing? Proponents of the Steady
e cosmology answer that it comes from whatever place
ponents of the Big Bang get their Bang from. If we can
gine all the matter in the universe discontinuously
ted from nothing 15 billion to 20 billion years ago, why
we unable to imagine it being created in a tenuous
kle everywhere, continuously and forever? If the Steady
e hypothesis is true, there was never a time when the
xies were much closer. The universe in its largest struc-
s is then unchanging and infinitely old.

But as placid and, in a strange way, as satisfying as t
Steady State cosmology is, there is strong evidence against
Whenever a sensitive radio telescope is pointed anywhere
the sky, the constant chatter of a kind of cosmic static c
be detected. The characteristics of this radio noise mat
almost exactly what we would expect if the early unive
was hot and filled with radiation in addition to matt
The cosmic black-body radiation is very nearly the sa
everywhere in the sky and looks very much to be the dista
rumblings of the Big Bang, cooled and enfeebled by t
expansion of the universe but coursing still down t
corridors of time. The primeval fireball, the explosive eve
that initiated the expanding universe, can be observe
Supporters of the Steady State cosmology must now
reduced to positing a large number of special sources
radiation which together somehow mimic exactly the cool
primeval fireball, or proposing that the universe far beyo
the event horizon is steady state but, by a peculiar accide
we live in a kind of expanding bubble, a violent pimp
in a much vaster but more placid universe. This idea h
the advantage or flaw, depending on your point of vie
of being impossible to disprove by any conceivable expe
ment, and virtually all cosmologists have abandoned t
Steady State hypothesis.

If the universe is not in a steady state, then it is changin
and such changing universes are described by evolutiona
cosmologies. They begin in one state, and they end
another. What are the possible fates of the universe
evolutionary cosmologies? If the universe continues
expand at its present rate and galaxies continue to disappe
over the event horizon, there will eventually be less and le
matter in the visible universe. The distances between galaxi
will increase, and there will be fewer and fewer of the spir
nebulae for the successors of Slipher, Hubbell and Humaso
to view. Eventually the distance from our Galaxy to th

est galaxy will exceed the distance to the event horizon, astronomers will no longer be able to see even the rest galaxy except in (very) old books and photographs. use of the gravity that holds the stars in our Galaxy ther, the expanding universe will not dissipate our axy, but even here a strange and desolate fate awaits For one thing, the stars are evolving, and in tens or dreds of billions of years most present stars will have me small and dark dwarf stars. The remainder will have psed to neutron stars or black holes. No new matter be available for a vigorous younger generation of stars. Sun, the stars, the entire Milky Way Galaxy, will ly turn off. The lights in the night sky will go out.

ut in such a universe there is a further evolution still. are used to the idea of radioactive elements, certain kinds toms that spontaneously decay or fall to pieces. Ordinary nium is one example. But we are less familiar with the that every atom except iron is radioactive, given a long ugh period of time. Even the most stable atoms will oactively decay, emit alpha and other particles, and to pieces, leaving only iron, if we wait long enough. v long? The American physicist Freeman Dyson of the itute for Advanced Study calculates that the half-life of is about 10^{500} years, a one followed by five hundred s – a number so large that it would take a dedicated erologist the better part of ten minutes just to write it n. So if we wait just a little longer – 10^{600} years would ust fine – not only would the stars have gone out, but all matter in the universe not in neutron stars or black s would have decayed into the ultimate nuclear dust. ntually, galaxies will have vanished altogether. Suns will e blackened, matter disintegrated, and no conceivable ibility will remain for the survival of life or intelligence vilizations – a cold and dark and desolate death of the erse.

But need the universe expand forever? If I stand on small asteroid and throw a rock up, it will leave the asteroid there being on such a worldlet not enough gravity to dra the rock back. If I throw the same rock at the same spee from the surface of the Earth, it will of course turn aroun and fall down because of the substantial gravity of ou planet. But the same sort of physics applies to the univers as a whole. If there is less than a certain amount of matte each galaxy will feel an insufficient tug from the gravi tational attraction of the others to be slowed down ap preciably, and the expansion of the universe will continu forever. On the other hand, if there is more than a certai critical mass, the expansion will eventually slow, and we wi be saved from the desolation teleology of a universe tha expands forever.

What, then, would be the fate of the universe? Why, the an observer would see expansion eventually replaced b contraction, the galaxies slowly and then at an ever increasing pace approaching one another, a careening devastating smashing together of galaxies, worlds, life civilizations and matter until every structure in the univers is utterly destroyed and all the matter in the cosmo converted into energy: instead of a universe ending in col and tenuous desolation, a universe finishing in a hot an dense fireball. It is very likely that such a fireball woul rebound, leading to a new expansion of the universe and if the laws of nature remain the same, a new incarnatio of matter, a new set of condensations of galaxies and star and planets, a new evolution of life and intelligence. Bu information from our universe would not trickle into tha next one and, from our vantage point, such an oscillatin cosmology is as definitive and depressing an end as th expansion that never stops.

The distinction between a Big Bang with expansion for ever and an Oscillating Universe clearly turns on the amoun

natter there is. If the critical amount of matter is eded, we live in an Oscillating Universe. Otherwise we in one that expands forever. The expansion times – sured in tens of billions of years – are so long that these nological issues do not affect any immediate human erns. But they are of the most profound import for our of the nature and fate of the universe and – only a little e remotely – of ourselves.

a remarkable scientific paper published in the Decem- 15, 1974 issue of the *Astrophysical Journal*, a wide range bservational evidence is brought to bear on the question whether the universe will continue to expand forever (an n' universe) or whether it will gradually slow down and ntract (a 'closed' universe), perhaps as part of an infinite s of oscillations. The work is by J. Richard Gott III and es E. Gunn, then both of the California Institute of hnology, and David N. Schramm and Beatrice M. ely, then of the University of Texas. In one of their uments they review calculations of the amount of mass nd between galaxies in 'nearby' well-observed regions of e and extrapolate to the rest of the universe: they find there is not enough matter to slow the expansion n.

rdinary hydrogen has a nucleus comprising a single ton. Heavy hydrogen, called deuterium, has a nucleus prising one proton and one neutron. An astonomical scope in Earth orbit called 'Copernicus' has measured, the first time, the amount of deuterium between the s. Deuterium must have been made in the Big Bang in mount that depends on the early density of the universe. early density of the universe is connected with the ent density of the universe. The amount of deuterium nd by 'Copernicus' implies a value to the early density he universe and suggests that the present density is fficient to prevent the universe from expanding for-

ever.* And what is said to be the best value of the Hubl constant – which specifies how much faster more dista galaxies are receding from us than nearby ones – is consiste with this whole story.

Gott and his colleagues stressed that there may be loo holes in their argument, that it may be possible to hi intergalactic matter in ways which we could not then dete Evidence for such missing mass has now begun to emerg The High Energy Astronomical Observatories (HEAO) a a set of satellites orbiting the Earth and scanning t universe for particles and radiation that we cannot dete down here, under our thick blanket of air. Satellites of th sort have detected intense emission of X-rays from cluste of galaxies, from intergalactic spaces where there w hitherto no hint of any matter. Extremely hot gas betwe the galaxies would be invisible to other experiment methods and therefore missed in the inventory of cosm matter made by Gott and his colleagues. What is mor ground-based radio astronomical studies with the Arecib Observatory in Puerto Rico have shown that the matter galaxies extends far beyond the optical light from th apparent edges of galaxies. When we look at a photograp of a galaxy, we see an edge or periphery beyond whic there is no apparent luminous matter. But the Arecib radio telescope has found that the matter fades off extreme slowly and that there is substantial dark matter in th peripheries and exteriors of galaxies, which had been misse by previous surveys.

The amount of missing matter required to make th universe ultimately collapse is substantial. It is thirty time the matter in standard inventories such as Gott's. But it ma

* But there is still a debate on how much deuterium can be made the hot insides of stars and later spewed back into the interstellar gas. this is substantial, the present deuterium abundance will have less impa on the density of the early universe.

hat the dark gas and dust in the galactic outskirts, the astonishingly hot gas glowing in X-rays between the xies, together constitute just enough matter to close the erse, prevent an expansion forever – but condemn us to revocable end in a cosmic fireball 50 billion or 100 n years hence. The issue is still teetering. The deuterium nce points the other way. Our inventories of mass are ar from complete. But as new observational techniques lop we will have the capability of detecting more and e of any missing mass, and so it would seem that the fulum is swinging towards a closed universe.

is a good idea not to make up our minds prematurely his issue. It is probably best not to let our personal erences influence the decision. Rather, in the long ition of successful science, we should permit nature to al the truth to us. But the pace of discovery is kening. The nature of the universe emerging from ern experimental cosmology is very different from that e ancient Greeks who speculated on the universe and gods. If we have avoided anthropocentrism; if we have and dispassionately considered all alternatives, it may hat in the next few decades we will, for the first time, rously determine the nature and fate of the universe. then we shall see if Gott knows.

CHAPTER 25

THE AMNIOTIC UNIVERSE

* * *

It is as natural to man to die as to be born; and to a little infant, perhaps, the one is as painful as the other.

FRANCIS BACON,
Of Death (1612)

The most beautiful thing we can experience is the mysterious. It is the source of all true art and science. He to whom this emotion is a stranger, who can no longer wonder and stand rapt in awe, is as good as dead: his eyes are closed.... To know that what is impenetrable to us really exists, manifesting itself as the highest wisdom and the most radiant beauty which our dull facilities can comprehend only in the most primitive forms – this knowledge, this feeling, is at the centre of true religiousness. In this sense, and in this sense only, I belong to the ranks of the devoutly religious men.

ALBERT EINSTEIN,
What I Believe (1930)

WILLIAM WOLCOTT died and went to heaven. Or so it seeme
Before being wheeled to the operating table, he had bee
reminded that the surgical procedure would entail a certai
risk. The operation was a success, but just as the anaesthes
was wearing off his heart went into fibrillation and he die
It seemed to him that he had somehow left his body an
was able to look down upon it, withered and patheti
covered only by a sheet, lying on a hard and unforgivin
surface. He was only a little sad, regarded his body one la
time – from a great height, it seemed – and continued a kin
of upward journey. While his surroundings had bee

fused by a strange permeating darkness, he realized that
.igs were now getting brighter – looking up, you might
. And then he was being illuminated from a distance,
oded with light. He entered a kind of radiant kingdom
! there, just ahead of him, he could make out in silhouette,
gnificently lit from behind, a great godlike figure whom
was now effortlessly approaching. Wolcott strained to
ke out His face ...

And then awoke. In the hospital operating room where
defibrillation machine had been rushed to him, he had
n resuscitated at the last possible moment. Actually, his
rt had stopped, and by some definitions of this poorly
lerstood process, he had died. Wolcott was certain that
had died, that he had been vouchsafed a glimpse of
after death and a confirmation of Judaeo-Christian
ology.

Similar experiences, now widely documented by phy-
ans and others, have occurred all over the world. These
ithanatic, or near-death, epiphanies have been ex-
ienced not only by people of conventional Western
giosity but also by Hindus and Buddhists and sceptics.
eems plausible that many of our conventional ideas about
ven are derived from such near-death experiences, which
st have been related regularly over the millennia. No
vs could have been more interesting or more hopeful than
t of the traveller returned, the report that there is a voyage
a life after death, that there is a God who awaits us,
that upon death we feel grateful and uplifted, awed
overwhelmed.

For all I know, these experiences may be just what they
m and a vindication of the pious faith that has taken
h a pummelling from science in the past few centuries.
sonally, I would be delighted if there were a life after
th – especially if it permitted me to continue to learn
out this world and others, if it gave me a chance to

discover how history turns out. But I am also a scientist so I think about what other explanations are possible. How could it be that people of all ages, cultures and eschatological predispositions have the *same sort* of near-death experience?

We know that similar experiences can be induced with fair regularity, cross-culturally, by psychedelic drugs.* Out-of-body experiences are induced by dissociative anaesthetics such as the ketamines (2-[o-chlorophenyl]-2-[methylamino] cyclohexanones). The illusion of flying is induced by atropine and other belladonna alkaloids, and these molecules, obtained, for example, from mandrake or jimson weed, have been used regularly by European witches and North American *curanderos* ('healers') to experience, in the midst of religious ecstasy, soaring and glorious flight. MDA (2,4-methylenedioxyamphetamine) tends to induce age regression, an accessing of experiences from youth and infancy which we had thought entirely forgotten. DMT (N,N-dimethyltryptamine) induces micropsia and macropsia, the sense of the world shrinking or expanding, respectively –

* It is interesting to wonder why psychedelic molecules exist – especially in great abundance – in a variety of plants. The psychedelics are unlikely to provide any immediate benefit for the plant. The hemp plant probably does not get high from its complement of $^{1}\Delta$ tetrahydrocannabinol. But human beings *cultivate* hemp because the hallucinogenic properties of marijuana are widely prized. There is evidence that in some cultures psychedelic plants are the only domesticated vegetation. It is possible that in such ethnobotany a symbiotic relationship has developed between the plants and the humans. Those plants which by accident provide desired psychedelics are preferentially cultivated. Such artificial selection can exert an extremely powerful influence on subsequent evolution in relatively short time periods – say, tens of thousands of years – as is apparent by comparing many domesticated animals with their wild forebears. Recent work also makes it likely that psychedelic substances work because they are close chemical congeners of natural substances, produced by the brain, which inhibit or enhance neural transmission, and which may have among their physiological functions the induction of endogenous changes in perception or mood.

ittle like what happens to Alice after she obeys in-uctions on small containers reading 'Eat me' or 'Drink '. LSD (lysergic acid diethylamide) induces a sense of on with the universe, as in the identification of Brahman h Atman in Hindu religious belief.

Can it really be that the Hindu mystical experience is -wired into us, requiring only 200 micrograms of LSD to made manifest? If something like ketamine is released in es of mortal danger or near-death, and people returning m such an experience always provide the same account heaven and God, then must there not be a sense in which sterns as well as Eastern religions are hard-wired in the ronal architecture of our brains?

t is difficult to see why evolution should have selected ins that are predisposed to such experiences, since no e seems to die or fail to reproduce from a want of mystic vour. Might these drug-inducible experiences as well as near-death epiphany be due merely to some evolu-narily neutral wiring defect in the brain which, by ident, occasionally brings forth altered perceptions of the rld? That possibility, it seems to me, is extremely im-usible, and perhaps no more than a desperate rationalist empt to avoid a serious encounter with the mystical.

The only alternative, so far as I can see, is that every man being, without exception, has already shared an erience like that of those travellers who return from the d of death: the sensation of flight; the emergence from kness into light; an experience in which, at least some-es, a heroic figure can be dimly perceived, bathed in liance and glory. There is only one common experience t matches this description. It is called birth.

NAME IS STANISLAV GROF. In some pronounciations his t and last names rhyme. He is a physician and a chiatrist who has, for more than twenty years, employed

LSD and other psychedelic drugs in psychotherapy. Hi work long antedates the American drug culture, havin begun in Prague, Czechoslovakia, in 1956 and continuin in recent years in the slightly different cultural setting o Baltimore, Maryland. Grof probably has more continuin scientific experience on the effects of psychedelic drugs o patients than anyone else.* He stresses that whereas LSI can be used for recreational and aesthetic purposes, it ca have other and more profound effects, one of which is th accurate recollection of perinatal experiences. 'Perinatal' is neologism for 'around birth', and is intended to apply no just to the time immediately after birth but to the time befor as well. (It is a parallel construction to 'perithanatic', near death.) He reports a large number of patients who, afte a suitable number of sessions, actually re-experience rathe than merely recollect profound experiences, long gone an considered intractable to our imperfect memories, fro perinatal times. This is, in fact, a fairly common LSI experience, by no means limited to Grof's patients.

Grof distinguishes four perinatal stages recovered unde psychedelic therapy. Stage 1 is the blissful complacency o the child in the womb, free of all anxiety, the centre of small, dark, warm universe – a cosmos in an amniotic sac In its intrauterine state the foetus seems to experience some thing very close to the oceanic ecstasy described by Freu as a fount of the religious sensibility. The foetus is, of course moving. Just before birth it is probably as alert, perhap even more alert, than just after birth. It does not seem

*A fascinating description of Grof's work and the entire range o psychedelics can be found in the forthcoming book *Psychedelic Drug Reconsidered* by Lester Grinspoon and James Bakalar (New York, Basi Books, 1979). Grof's own description of his findings can be found i *Realms of the Human Unconscious* by S. Grof (New York, E. P. Dutton 1976) and *The Human Encounter with Death* by S. Grof and J. Halifa (New York, E. P. Dutton, 1977).

ossible that we may occasionally and imperfectly ember this Edenic, golden age, when every need – for d, oxygen, warmth and waste disposal – was satisfied re it was sensed, provided automatically by a superbly gned life-support system; and, in dim recollection years , describe it as 'being one with the universe'.

Stage 2, the uterine contractions begin. The walls to ch the amniotic sac is anchored, the foundation of the le intrauterine environment, become traitorous. The us is dreadfully compressed. The universe seems to ate, a benign world suddenly converted into a cosmic ure chamber. The contractions may last intermittently hours. As time goes on, they become more intense. No e of surcease is offered. The foetus has done nothing to rve such a fate, an innocent whose cosmos has turned n it, administering seemingly endless agony. The severity his experience is apparent to anyone who has seen a natal cranial distortion that is still evident days after h. While I can understand a strong motivation to terate utterly any trace of this agony, might it not rface under stress? Might not, Grof asks, the hazy and essed memory of this experience prompt paranoid asies and explain our occasional human predilections for sm and masochism, for an identification of assailant and m, for that childlike zest for destruction in a world ch, for all we know, may tomorrow become terrifyingly redictable and unreliable? Grof finds recollections in the stage connected with images of tidal waves and earth-kes, the analogues in the physical world of the intra-ine betrayal.

age 3 is the end of the birth process, when the child's d has penetrated the cervix and might, even if the eyes closed, perceive a tunnel illuminated at one end and e the brilliant radiance of the extrauterine world. The overy of light for a creature that has lived its entire

existence in darkness must be a profound and on some lev an unforgettable experience. And there, dimly made out b the low resolution of the newborn's eyes, is some godlik figure surrounded by a halo of light – the Midwife or th Obstetrician or the Father. At the end of a monstrou travail, the baby flies away from the uterine universe, an rises towards the lights and the gods.

Stage 4 is the time immediately after birth when th perinatal apnea has dissipated, when the child is blankete or swaddled, hugged and given nourishment. If recollecte accurately, the contrast between Stages 1 and 2 and 2 and 4 for an infant utterly without other experience, must b very deep and striking; and the importance of Stage 3 as th passage between agony and at least a tender simulacrun of the cosmic unity of Stage 1 must have a powerfu influence on the child's later view of the world.

There is, of course, room for scepticism in Grof's accoun and in my expansion upon it. There are many question to be answered. Do children born before labour b Caesarean section never recall the agonizing Stage 2? Unde psychedelic therapy, do they report fewer images of catas trophic earthquakes and tidal waves than those born b normal deliveries? Conversely, are children born after th particularly severe uterine contractions induced in 'electiv labour' by the hormone oxytocin* more likely to acquire th psychological burdens of Stage 2? If the mother is given strong sedative, will the baby upon maturity recall a ver

*Astonishingly, oxytocin turns out to be an ergot derivative that chemically related to psychedelics such as LSD. Since it induces labou it is at least a plausible hypothesis that some similar natural substance employed by nature to induce uterine contractions. But this would imp some fundamental connection for the mother – and perhaps for the child between birth and psychedelic drugs. Perhaps it is therefore not s implausible that, much later in life under the influence of a psychedel drug, we recall the birth experience – the event during which we fir experienced psychedelic drugs.

rent transition from Stage 1 directly to Stage 4 and never
rt, in a perithanatic experience, a radiant epiphany?
neonates resolve an image at the moment of birth or are
merely sensitive to light and darkness? Might the
ription, in the near-death experience, of a fuzzy and
ing god without hard edges be a perfect recollection of
nperfect neonatal image? Are Grof's patients selected
the widest possible range of human beings or are these
unts restricted to an unrepresentative subset of the
an community?

is easy to understand that there might be more personal
ctions to these ideas, a resistance perhaps similar to the
of chauvinism that can be detected in justifications of
ivorous eating habits: the lobsters have no central
ous system; they don't mind being dropped alive into
ing water. Well, maybe. But the lobster-eaters have a
ed interest in this particular hypothesis on the neuro-
siology of pain. In the same way I wonder if most
lts do not have a vested interest in believing that infants
ess very limited powers of perception and memory,
there is no way the birth experience could have a
found and, in particular, a profoundly negative in-
nce.

Grof is right about all this, we must ask why such
llections are possible – why, if the perinatal experience
produced enormous unhappiness, evolution has not
cted out the negative psychological consequences. There
some things that newborn infants must do. They must
good at sucking; otherwise they will die. They must,
nd large, look cute because at least in previous epochs
human history, infants who in some way seemed
ealing were better taken care of. But *must* newborn
ies see images of their environment? *Must* they remember
horrors of the perinatal experience? In what sense is
e survival value in that? The answer might be that the

pros outweigh the cons – perhaps the loss of a universe t which we are perfectly adjusted motivates us powerfully t change the world and improve the human circumstance Perhaps that striving, questing aspect of the human spiri would be absent if it were not for the horrors of birth.

I am fascinated by the point – which I stress in my book *The Dragons of Eden* – that the pain of childbirth i especially marked in human mothers because of th enormous recent growth of the brain in the last few millio years. It would seem that our intelligence is the source o our unhappiness in an almost literal way; but it would als imply that our unhappiness is the source of our strength a a species.

These ideas may cast some light on the origin and natur of religion. Most Western religions long for a life after death Eastern religions for relief from an extended cycle of death and rebirths. But both promise a heaven or satori, a idyllic reunion of the individual and the universe, a return t Stage 1. Every birth is a death – the child leaves th amniotic world. But devotees of reincarnation claim tha every death is a birth – a proposition that could have bee triggered by perithanatic experiences in which the perinata memory was recognized as a recollection of birth. ('There was a faint rap on the coffin. We opened it, and it turned out that Abdul had not died. He had awakened from a long illness which had cast its spell upon him, and he told a strange story of being born once again.')

Might not the Western fascination with punishment and redemption be a poignant attempt to make sense of perinata Stage 2? Is it not better to be punished for something – no matter how implausible, such as original sin – than fo nothing? And Stage 3 looks very much like a common experience, shared by all human beings, implanted into our earliest memories and occasionally retrieved in such religious epiphanies as the near-death experience. It i

ting to try to understand other puzzling religious motifs
ese terms. *In utero* we know virtually nothing. In Stage
foetus gains experience of what might very well in later
e called evil – and then is forced to leave the uterus.
is entrancingly close to eating the fruit of the tree of the
vledge of good and evil and then experiencing the
ulsion' from Eden.* In Michelangelo's famous painting
ne ceiling of the Sistine Chapel, is the finger of God
bstetrical finger? Why is baptism, especially total-
ersion baptism, widely considered a symbolic rebirth?
oly water a metaphor for amniotic fluid? Is not the
e concept of baptism and the 'born again' experience
xplicit acknowledgment of the connection between birth
mystical religiosity?

we study some of the thousands of religions on the
et Earth, we are impressed by their diversity. At least
e of them seem stupefyingly harebrained. In doctrinal
ils, mutual agreement is rare. But many great and good
and women have stated that behind the apparent
rgences is a fundamental and important unity; beneath
doctrinal idiocies is a basic and essential truth. There
two very different approaches to a consideration of
ts of belief. On the one hand, there are the believers,
are often credulous, and who accept a received religion
ally, even though it may have internal inconsistencies or
n strong variance with what we know reliably about the
rnal world or ourselves. On the other hand, there are
stern sceptics, who find the whole business a farrago of
k-minded nonsense. Some who consider themselves
r rationalists resist even considering the enormous
ous of recorded religious experience. These mystical
ghts must mean something. But what? Human beings
by and large, intelligent and creative, good at figuring

different but not inconsistent hypothesis on the Eden metaphor, in
geny rather than ontogeny, is described in *The Dragons of Eden.*

things out. If religions are fundamentally silly, why is it tha so many people believe in them?

Certainly, bureaucratic religions have throughout huma history allied themselves with the secular authorities, an it has frequently been to the benefit of those ruling a natio to inculcate the faith. In India, when the Brahmans wishe to keep the 'untouchables' in slavery, they proffered divin justification. The same self-serving argument was employe by whites, who actually described themselves as Christians in the ante-bellum American South to support the enslave ment of blacks. The ancient Hebrews cited God's directio and encouragement in the random pillage and murder the sometimes visited on innocent peoples. In medieval time the Church held out the hope of a glorious life after deat to those upon whom it urged contentment with their lowl and impoverished station. These examples can be multiplie indefinitely, to include virtually all the world's religions We can understand why the oligarchy might favou religion when, as is often the case, religion justifies oppres sion – as Plato, a dedicated advocate of book-burning, di in the *Republic*. But why do the oppressed so eagerly g along with these theocratic doctrines?

The general acceptance of religious ideas, it seems to me can only be because there is something in them tha resonates with our own certain knowledge – something dee and wistful; something every person recognizes as central t our being. And that common thread, I propose, is birth Religion is fundamentally mystical, the gods inscrutable, th tenets appealing but unsound because, I suggest, blurre perceptions and vague premonitions are the best that th newborn infant can manage. I think that the mystical cor of the religious experience is neither literally true no perniciously wrong-minded. It is rather a courageous flawed attempt to make contact with the earliest and mos profound experience of our lives. Religious doctrine

mentally clouded because not a single person has ever th had the skills of recollection and retelling necessary liver a coherent account of the event. All successful ons seem at their nucleus to make an unstated and ps even unconscious resonance with the perinatal ence. Perhaps when secular influences are subtracted, emerge that the most successful religions are those perform this resonance best.

empts at rationalistic explanations of religious belief been resisted vigorously. Voltaire argued that if God ot exist Man would be obliged to invent him, and was d for the remark. Freud proposed that a paternalistic is partly our projection as adults of our perceptions fathers when we were infants; he also called his book igion *The Future of an Illusion*. He was not despised as as we might imagine for these views, but perhaps because he had already demonstrated his disreputa- by introducing such scandalous notions as infantile ility.

y is the opposition to rational discourse and reasoned nent in religion so strong? In part, I think it is because common perinatal experiences are real but resist ate recollection. But another reason, I think, has to do the fear of death. Human beings and our immediate tors and collateral relatives, such as the Neanderthals, robably the first organisms on this planet to have a awareness of the inevitability of our own end. We will nd we fear death. This fear is worldwide and trans- ral. It probably has significant survival value. Those wish to postpone or avoid death can improve the l, reduce its perils, make children who will live after us, reate great works by which they will be remembered. e who propose rational and sceptical discourse on religious are perceived as challenging the remaining y held solution to the human fear of death, the hypo-

thesis that the soul lives on after the body's demise.* Sin
we feel strongly, most of us, about wishing not to die, w
are made uncomfortable by those who suggest that death
the end; that the personality and the soul of each of us wi
not live on. But the soul hypothesis and the God hypothes
are separable; indeed, there are some human cultures
which the one can be found without the other. In any cas
we do not advance the human cause by refusing to consid
ideas that make us frightened.

Those who raise questions about the God hypothesis an
the soul hypothesis are by no means all atheists. An athei
is someone who is certain that God does not exist, someon
who has compelling evidence against the existence of Go
I know of no such compelling evidence. Because God ca
be relegated to remote times and places and to ultima
causes, we would have to know a great deal more about th
universe than we do now to be sure that no such Go
exists. To be certain of the existence of God and to b
certain of the nonexistence of God seem to me to be th
confident extremes in a subject so riddled with doubt an
uncertainty as to inspire very little confidence indeed. A wid
range of intermediate positions seems admissible, and con
sidering the enormous emotional energies with which th
subject is invested, a questing, courageous and open min
seems to be the essential tool for narrowing the range of ou
collective ignorance on the subject of the existence of Go

* One curious variant is given in Arthur Schnitzler's *Flight Into Darkne*
'... at all the moments of death of any nature, one lives over again his pa
life with a rapidity inconceivable to others. This remembered life must al
have a last moment, and this last moment its own last moment, and
on, and hence, dying is itself eternity, and hence, in accordance with t
theory of limits, one may approach death but can never reach it.' In fa
the sum of an infinite series of this sort is finite, and the argument fa
for mathematical as well as other reasons. But it is a useful remind
that we are often willing to accept desperate measures to avoid a serio
confrontation with the inevitability of death.

nen I give lectures on borderline or pseudo or folk
ce (along the lines of Chapters 5 through 8 of this book)
sometimes asked if similar criticism should not be
ed to religious doctrine. My answer is, of course, yes.
lom of religion, one of the rocks upon which the United
s was founded, is essential for free inquiry. But it does
arry with it any immunity from criticism or reinterpre-
n for the religions themselves. The words 'question' and
t' are cognates. Only through inquiry can we discover
. I do not insist that these connections between religion
perinatal experience are correct or original. Many of
are at least implicit in the ideas of Stanislav Grof and
sychoanalytic school of psychiatry, particularly Otto
, Sandor Ferenczi and Sigmund Freud. But they are
h thinking about.

ere is, of course, a great deal more to the origin of
ion than these simple ideas suggest. I do not propose
theology is physiology entirely. But it would be
nishing, assuming we really can remember our perinatal
riences, if they did not affect in the deepest way our
ides on birth and death, sex and childhood, on purpose
ethics, on causality and God.

COSMOLOGY. Astronomers studying the nature and
n and fate of the universe make elaborate observations,
ribe the cosmos in differential equations and the tensor
lus, examine the universe from X-rays to radio waves,
t the galaxies and determine their motions and distances
l when all is done a choice is to be made between three
rent views: a Steady State cosmology, blissful and quiet;
scillating Universe, in which the universe expands and
racts, painfully and forever; and a Big Bang expanding
erse, in which the cosmos is created in a violent event,
sed with radiation ('Let there be light') and then grows
cools, evolves and becomes quiescent, as we saw in the

previous chapter. But these three cosmologies resemble with an awkward, almost embarrassing precision the human perinatal experiences of Grof's Stages 1, 2, and 3 plus 4 respectively.

It is easy for modern astronomers to make fun of the cosmologies of other cultures – for example, the Dogon idea that the universe was hatched from a cosmic egg (Chapter 6). But in light of the ideas just presented, I intend to be much more circumspect in my attitudes towards folk cosmologies; their anthropocentrism is just a little bit easier to discern than ours. Might the puzzling Babylonian and Biblical references to waters above and below the firmament, which Thomas Aquinas struggled so painfully to reconcile with Aristotelian physics, be merely an amniotic metaphor? Are we incapable of constructing a cosmology that is not some mathematical encrypting of our own personal origins?

Einstein's equations of general relativity admit a solution in which the universe expands. But Einstein, inexplicably, overlooked such a solution and opted for an absolutely static, nonevolving cosmos. Is it too much to inquire whether this oversight had perinatal rather than mathematical origins? There is a demonstrated reluctance of physicists and astronomers to accept Big Bang cosmologies in which the universe expands forever, although conventional Western theologians are more or less delighted with the prospect. Might this dispute, based almost certainly on psychological predispositions, be understood in Grofian terms?

I do not know how close the analogies are between personal perinatal experiences and particular cosmological models. I suppose it is too much to hope that the originators of the Steady State hypothesis were each born by Caesarean section. But the analogies are very close, and the possible connection between psychiatry and cosmology seems very real. Can it really be that every possible mode of origin and

ıtion of the universe corresponds to a human perinatal rience? Are we such limited creatures that we are unable nstruct a cosmology that differs significantly from one e perinatal stages?* Is our ability to know the universe lessly ensnared and enmired in the experiences of birth infancy? Are we doomed to recapitulate our origins in etence of understanding the universe? Or might the rging observational evidence gradually force us into an mmodation with and an understanding of that vast and ome universe in which we float, lost and brave and ting?

is customary in the world's religion to describe Earth ur mother and the sky as our father. This is true of ıus and Gaea in Greek mythology, and also among ve Americans, Africans, Polynesians, indeed most of the les of the planet Earth. However, the very point of the ıatal experience is that we leave our mothers. We do it at birth and then again when we set out into the world urselves. As painful as those leave-takings are, they are ıtial for the continuance of the human species. Might fact have some bearing on the almost mystical appeal space flight has, at least for many of us? Is it not a ng of Mother Earth, the world of our origins, to seek fortune among the stars? This is precisely the final visual phor of the film *2001: A Space Odyssey*. Konstantin lkovsky was a Russian schoolmaster, almost entirely

angaroos are born when they are little more than embryos and must nake, entirely unassisted, a heroic journey hand over hand from birth to pouch. Many fail this demanding test. Those who succeed find elves once again in a warm, dark and protective environment, this quipped with teats. Would the religion of a species of intelligent upials invoke a stern and implacable god who severely tests marsupial- Would marsupial cosmology deduce a brief interlude of radiation in a ıture Big Bang followed by a 'Second Dark', and then a much more emergence into the universe we know?

self-educated, who, around the turn of the century, formulated many of the theoretical steps that have since been taken in the development of rocket propulsion and space flight. Tsiolkovsky wrote: 'The Earth is the cradle of mankind. But one does not live in the cradle forever.'

We are set irrevocably, I believe, on a path that will take us to the stars – unless in some monstrous capitulation to stupidity and greed, we destroy ourselves first. And out there in the depths of space, it seems very likely that, sooner or later, we will find other intelligent beings. Some of them will be less advanced than we; some, probably most, will be more. Will all the spacefaring beings, I wonder, be creatures whose births are painful? The beings more advanced than we will have capabilities far beyond our understanding. In some very real sense they will appear to us as godlike. There will be a great deal of growing up required of the infant human species. Perhaps our descendants in those remote times will look back on us, on the long and wandering journey the human race will have taken from its dimly remembered origins on the distant planet Earth, and recollect our personal and collective histories, our romance with science and religion, with clarity and understanding and love.

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APPENDICES TO CHAPTER 7

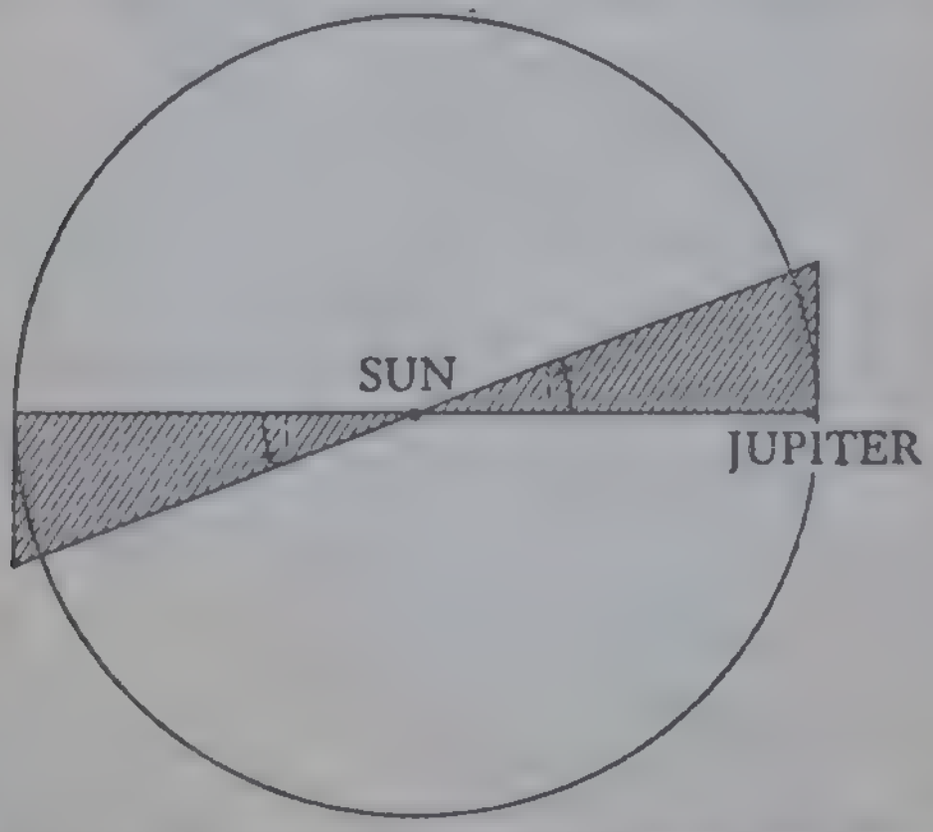
APPENDIX 1

Simple Collision Physics Discussion of the Probability of a Recent Collision with the Earth by a Massive Member of the Solar System

HERE CONSIDER the probability that a massive object of the sort sidered by Velikovsky to be ejected from Jupiter might impact th. Velikovsky proposes that a grazing or near-collision urred between this comet and the Earth. We will subsume this under the designation 'collision' below. Consider a spherical ct of radius R moving among other objects of similar size. lision will occur when the centres of the objects are 2R distant. may then speak of an effective collision cross section of $\pi(2R)^2 = 4\pi R^2$; this is the target area which the centre of the ving object must strike in order for a collision to occur. Let assume that only one such object (Velikovsky's comet) is ving and that the others (the planets in the inner solar system) stationary. This neglect of the motion of the planets of the r solar system can be shown to introduce errors smaller than a or of 2. Let the comet be moving at a velocity v and let the e density of potential targets (the planets of the inner solar em) be n. We will use units in which R is in centimetres (cm), in cm^2, v is in cm/sec, and n is in planets per cm^3; n is iously a very small number.

While comets have a wide range of orbital inclinations to the otic plane, we will be making the most generous assumptions for kovsky's hypothesis if we assume the smallest plausible value this inclination. If there were no restriction on the orbital nation of the comet, it would have equal likelihood of moving where in a volume centred on the Sun and of radius r = 5 onomical units (1 a.u. = 1.5×10^{13} cm), the semi-major axis of orbit of Jupiter. The larger the volume in which the comet

can move, the less likely is any collision of it with another object. Because of Jupiter's rapid rotation, any object flung out from its interior will have a tendency to move in the planet's equatorial plane, which is inclined by 1.2° to the plane of the Earth's revolution about the Sun. However, for the comet to reach the inner part of the solar system at all, the ejection event must be sufficiently energetic that virtually any value of its orbital inclination, i, is plausible. A generous lower limit is then $i = 1.2°$. We therefore consider the comet to move (see diagram) in an orbit contained somewhere in a wedge-shaped volume, centred on the Sun (the comet's orbit must have the Sun at one focus), and of half-angle i. Its volume is then $(4/3)\pi r^3 \sin i = 4 \times 10^{40}$ cm^3, only 2 percent the full volume of a sphere of radius r. Since in that volume there are (disregarding the asteroids) three or four planets, the space density of targets relevant for our problem is about 10^{-40} planets/cm^3. A typical relative velocity of a comet or other object moving on an eccentric orbit in the inner solar system might be about 20 km/sec. The radius of the Earth is $R = 6.3 \times 10^8$ cm, which is almost exactly the radius of the planet Venus as well.



Wedge-shaped volume occupied by Velikovsky's comet.

Now let us imagine that the elliptical path of the comet is, in our mind's eye, straightened out, and that it travels from some time T

it impacts a planet. During that time it will have carved out
naginary tunnel behind it of volume σvT cm^3, and in that
ne there must be just one planet. But $1/n$ is also the volume
ining one planet. Therefore, the two quantities are equal and

$$T = (n\sigma v)^{-1};$$

alled the mean free time.
reality, of course, the comet will be travelling on an elliptical
, and the time for collision will be influenced to some degree
ravitational forces. However, it is easy to show (see, for
ple, Urey, 1951) that for typical values of v and relatively brief
sions of solar system history such as Velikovsky is consider-
he gravitational effects are to increase the effective collision
, section σ by a small quantity, and a rough calculation using
bove equation must give approximately the right results.
e objects which have, since the earliest history of the solar
m, produced impact craters on the Moon, Earth and the inner
ts are ones in highly eccentric orbits: the comets and,
ially, the Apollo objects – which are either dead comets or
oids. Using simple equations for the mean free time, astron-
s are able to account to good accuracy for, say, the number
aters on the Moon, Mercury or Mars produced since the
ation of these objects: they are the results of the occasional
ion of an Apollo object or, more rarely, a comet with the
r or planetary surface. Likewise, the equation predicts cor-
y the age of the most recent impact craters on Earth such
eteor Crater, Arizona. These quantitative agreements between
rvations and simple collision physics provide some substantial
ance that the same considerations properly apply to the
nt problem.
e are now able to make some calculations with regard to
ovsky's fundamental hypothesis. At the present time there are
Apollo objects with diameters larger than a few tens of
netres. The sizes of objects in the asteroid belt, and indeed any-
e else where collisions determine sizes, are understood by
ninution physics. The number of objects in a given size
e is proportional to the radius of the object to some negative

power, usually in the range of 2 to 4. If, therefore, Velikovsky'
proto-Venus comet were a member of some family of objects lik
the Apollo objects or the comets, the chance of finding on
Velikovskian comet 6,000 km in radius would be far less tha
one-millionth of the chance of finding one some 10 km in radiu
A more probable number is a billion times less likely, but let u
give the benefit of the doubt to Velikovsky.

Since there are about ten Apollo objects larger than about 10 k
in radius, the chance of there being one Velikovskian comet
then much less than 100,000-to-1 odds against the proposition
The steady-state abundance of such an object would then be (fo
$r = 4$ a.u., and $i = 1.2°$) $n = (10 \times 10^{-5})/4 \times 10^{40} = 2.5 \times 10^{-4}$
Velikovskian comets/cm^3. The mean free time for collision wit
Earth would then be $T = 1/(n\sigma v) = 1/[(2.5 \times 10^{-45}\ \text{cm}^{-3}) \times (5 \times$
$10^{18}\ \text{cm}^2) \times (2 \times 10^6\ \text{cm sec}^{-1})] = 4 \times 10^{21}$ secs $\simeq 10^{14}$ yea
which is much greater than the age of the solar system (5×10
years). That is, if the Velikovskian comet were part of th
population of other colliding debris in the inner solar system,
would be such a rare object that it would essentially never collid
with Earth.

But instead, let us grant Velikovsky's hypothesis for the sake o
argument and ask how long his comet would require, after ejectio
from Jupiter, to collide with a planet in the inner solar systen
Then, n applies to the abundance of planetary targets rather tha
Velikovskian comets, and $T = 1/[(10^{-40}\ \text{cm}^{-3}) \times (5 \times 10^{18}\ \text{cm}$
$\times (2 \times 10^6\ \text{cm sec}^{-1})] = 10^{15}$ secs $\simeq 3 \times 10^7$ years. Thus, th
chance of Velikovsky's 'comet' making a single full or grazin
collision with Earth within the last few thousand years is $(3 \times 10^4)/$
$(3 \times 10^7) = 10^{-3}$, or one chance in 1,000 – if it is independent o
the other debris populations. If it is part of such populations, th
odds rise to $(3 \times 10^4)/10^{14} = 3 \times 10^{-10}$, or one chance in
billion.

A more exact formulation of orbital-collision theory can b
found in the classic paper by Ernst Öpik (1951). He considers
target body of mass m_0 with orbital elements a_0, $e_0 = i_0 = 0$ in orb
about a central body of mass M. Then, a test body of mass
with orbital elements a, e, i and period P has a characteristic tim
T before approaching within distance R of the target body, whe

$$\frac{T}{P} \simeq \frac{\pi \sin i |U_x/U|}{Q^2[1 + 2(m_0 + m)/MQU]}$$

$$A = a/a_0,\ Q = R/a_0,$$

$$|U_x| = [2 - 1/A - A\ (1 - e^2)]1/2$$

$$U = \{3 - 1/A - 2[A(1 - e^2)1/2 \cos i\}^{1/2}$$

U is the relative velocity 'at infinity' and U_x is its component g the line of nodes.

R is taken as the physical radius of the planet, then

	Venus	*Earth*	*Mars*	*Jupiter*
10^5	5.6	4.3	1.5	8.8
MQ	0.088	0.14	0.043	21.6

application of Öpik's results to the present problem, the tions reduce to the following approximation:

$$\frac{T}{P} \simeq \frac{\pi \sin i}{Q^2}$$

g $P \simeq 5$ years ($a \simeq 3$ a.u.), we have

$$T \simeq 9 \times 10^9 \sin i \text{ years},$$

out 1/3 the mean free path lifetime from the simpler argument e.

ote that in both calculations, an approach to within N Earth has N^2 times the probability of a physical collision. Thus, $N = 10$, a miss of 63,000 km, the above values of T must be ced by two orders of magnitude. This is about 1/6 the distance een the Earth and the Moon.

or the Velikovskian scenario to apply, a closer approach is ssary: the book, after all, is called *Worlds in Collision*. Also, it imed (page 72) that, as a result of the passage of Venus by Earth, the oceans were piled to a height of 1,600 miles. From it is easy to calculate backwards from simple tidal theory (the

tide height is proportional to M/r^3, where M is the mass of Ven and r the distance between the planets during the encounter) th Velikovsky is talking about a grazing collision: the surfaces o Earth and Venus scrape! But note that even a 63,000-km miss doe not extricate the hypothesis from the collision physics problem as outlined in this appendix.

Finally, we observe that an orbit which intersects those of Jupiter and Earth implies a high probability of a close reapproach to Jupiter which would eject the object from the solar system before a near-encounter with Earth – a natural example of the trajectory of the Pioneer 10 spacecraft. Therefore, the present existence of the planet Venus must imply that the Velikovskian comet made few subsequent passages to Jupiter, and therefore that its orbit was circularized rapidly. (That there seems to be no way to accomplish such rapid circularization is discussed in the text.) Accordingly, Velikovsky must suppose that the comet's close encounter with Earth occurred soon after its ejection from Jupiter – consistent with the above calculations.

The probability, then, that the comet would have impacted the Earth only some tens of years after its ejection from Jupiter is between one chance in 1 million and one chance in 3 trillion, on the two assumptions on membership in existing debris populations. Even if we were to suppose that the comet was ejected from Jupiter as Velikovsky says, and make the unlikely assumption that it has no relation to any other objects which we see in the solar system today – that is, that smaller objects are never ejected from Jupiter – the mean time for it to have impacted Earth would be about 30 million years, inconsistent with his hypothesis by a factor of about 1 million. Even if we let his comet wander about the inner solar system for centuries before approaching the Earth, the statistics are still powerfully against Velikovsky's hypothesis. When we include the fact that Velikovsky believes in several statistically independent collisions in a few hundred years (see text), the net likelihood that his hypothesis is true becomes vanishing small. His repeated planetary encounters would require what might be called *Worlds in Collusion*.

APPENDIX 2

Consequences of a Sudden Deceleration of Earth's Rotation

). Now, Mr. Bryan, have you ever pondered what would have happened to the Earth if it had stood still?
. No. The God I believe in could have taken care of that, Mr. Darrow.
). Don't you know that it would have been converted into a molten mass of matter?
. You testify to that when you get on the stand. I will give you a chance.

The Scopes Trial, 1925

GRAVITATIONAL acceleration which holds us to the Earth's ce has a value of 10^3 cm sec^{-2} = 1 g. A deceleration of 10^{-2} g = 10 cm sec^{-2} is almost unnoticeable. How much time, uld Earth take to stop its rotation if the resulting deceleration unnoticeable? Earth's equatorial angular velocity is $\Omega = 2\pi/$ 7.3×10^{-5} radians/sec; the equatorial linear velocity is $R\Omega =$ km/sec. Thus, $\tau = R\Omega/a = 4600$ secs, or a little over an hour. e specific energy of the Earth's rotation is

$$E = \tfrac{1}{2}I\Omega^2/M \simeq \tfrac{1}{5}(R\Omega)^2 \simeq 4 \times 10^8 \text{ erg gm}^{-1},$$

e I is the Earth's principal moment of inertia. This is less than tent heat of fusion for silicates, $L \simeq 4 \times 10^9$ erg gm^{-1}. Thus, ence Darrow was wrong about the Earth melting. Nevertheless he was on the right track: thermal considerations are in fact to the Joshua story. With a typical specific heat capacity of 8×10^6 erg gm^{-1} deg^{-1}, the stopping and restarting of Earth e day would have imparted an *average* temperature increment $\Gamma \simeq 2E/c_p \simeq 100°K$, enough to raise the temperature above the al boiling point of water. It would have been even worse near urface and at low latitudes; with $v \simeq R\Omega$, $\Delta T \simeq v^2/c_p \simeq 240°K$. doubtful that the inhabitants would have failed to notice so atic a climatic change. The deceleration might be tolerable if ual enough, but not the heat.

APPENDIX 3

Present Temperature of Venus If Heated by a Close Passage to the Sun

THE HEATING of Venus by a presumed close passage by the Sun, and the planet's subsequent cooling by radiation to space are central to the Velikovskian thesis. But nowhere does he calculate either the amount of heating or the rate of cooling. However, at least a crude calculation can readily be performed. An object which grazes the solar photosphere must travel at very high velocities if it originates in the outer solar system: 500 km/sec is a typical value at perihelion passage. But the radius of the Sun is 7×10^{10} cm. Therefore a typical time scale for the heating of Velikovsky's comet is $(1.4 \times 10^{11}$ cm$)/(5 \times 10^{7}$ cm/sec$) \simeq 3000$ secs, which is less than an hour. The highest temperature the comet could possibly reach because of its close approach to the Sun is 6,000 K, the temperature of the solar photosphere. Velikovsky does not discuss any further sun-grazing events by his comet; subsequently it becomes the planet Venus, and cools to space – events which occupy, say, 3,500 years up to the present. But both heating and cooling occur radiatively, and the physics of both events is controlled in the same way by the Stefan-Boltzmann law of thermodynamics, according to which the amount of heating and the rate of cooling both are proportional to the temperture to the fourth power. Therefore the ratio of the temperature increment experienced by the comet in 3,000 secs of solar heating to its temperature decrement in 3,500 yrs of radiative cooling is $(3 \times 10^{3}$ secs$/10^{11}$ secs$)1/4 = 0.013$. The present temperature of Venus from this source would then be at most only $6{,}000 \times 0.013 = 79$ K, or about the temperature at which air freezes. Velikovsky's mechanism cannot keep Venus hot, even with very generous definitions of the word 'hot'.

The conclusion would not be altered materially were there to have been several close passes, rather than just one, through the solar photosphere. The source of the high temperature of Venus cannot be one or a few heating events, no matter how dramatic.

ot surface requires a continuous source of heat – which could ther endogenous (radioactive heating from the planetary or) or exogenous (sunlight). It is now evident, as suggested years ago (see Wildt, 1940; Sagan, 1960), that the latter is the it is the present radiation of the Sun, continuously falling nus, which is responsible for its high surface temperature.

APPENDIX 4

Magnetic Field Strengths Necessary to Circularize an Eccentric Cometary Orbit

OUGH VELIKOVSKY has not, we can calculate approximately the of magnitude of the magnetic field strength necessary to a significant perturbation on the motion of a comet. The rbing field might be from a planet, such as Earth or Mars, hich the comet is about to make a close approach, or from nterplanetary magnetic field. For this field to play an im- nt role, its energy density must be comparable to the kinetic y density of the comet. (We do not even worry about whether omet has a distribution of charges and fields which will it it to respond to the imposed field.) Thus, the condition is

$$\frac{B^2}{8\pi} = \frac{1/2\ mv^2}{(4/3)\ \pi R^3} = (1/2)\ \rho\ v^2$$

e B is the magnetic field strength in gauss, R is the radius of the t, m its mass, v its velocity and ρ its density. We note that the ition is independent of the mass of the comet. Taking a al cometary velocity in the inner solar system of about 25 ec, and ρ as the density of Venus, about 5 gm/cm^3, we find a magnetic field strength of over 10 million gauss is required. milar value in electrostatic units would apply if the circulariza- is electrical rather than magnetic.) Earth's equatorial surface is about 0.5 gauss. The fields of Mars and Venus are less 0.01 gauss. The Sun's field is several gauss, ranging up to al hundred gauss in sunspots. Jupiter's field as measured by

Pioneer 10 is less than 10 gauss. Typical interplanetary fields are 10^{-5} gauss. There is no way to generate anything approaching a 10 megagauss field on a large scale in the solar system. And there is no sign that such a field was ever experienced in the vicinity of Earth. We recall that the magnetic domains of molten rock in the course of refreezing are oriented by the prevailing field. Had Earth experienced, even fairly briefly, a 10 Mg field 3,500 years ago, rock magnetization evidence would show it clearly. It does not.

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